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Formal Modulation for Acoustic Performances of a Bridge

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In the last fifteen years in architecture the frequent use of design instruments such as algorithms, dynamical relations, parametric systems, mapping, morphogenesis, cellular automata and bifurcation with broken symmetry shows clearly how contemporary thinking in mathematics and physical sciences, dealing with complex dynamics, non-linear systems, chaos, emergent properties, resilience, etc., has changed the way we think about design and the life of today's cities.

> ' In a complex-structured city in which the interactions among parts intensify; in which the number of decision-makers and cultural scenarios overlap, interconnect, and sometimes collide; in which the temporal dimensions of the citizens are dissimilar; in which local and global, physical and virtual dimensions co-exist; it is necessary to respond with new typologies, new complex urban organisms and new production systems. Architects have to face different realities, in which building typologies and space-using modalities are continuously put into question. It becomes crucial to define a set of complex adaptive tools which are able to suitably manage these complexities within the system.'[1]

In the first phase architects' interest focused on the direct transposition into the architecture of digital tools deriving from other scientific fields. The use of such tools led architects to discover forms that were inconceivable with traditional procedures. Nevertheless, the lack of control of tools that were not specific to architecture engendered in the mid 1990s a drastic reduction in the initial interest in such an approach.

The motivation behind the interdisciplinary research Lab Non Linear Solutions Unit at the Graduate School of Planning and Preservation at Columbia University is to challenge, consolidate and promote research in the field of complex systems in architecture.

The pilot model, Applied Responsive Devices, is a methodological approach to the modelling and simulation of architecture and engineering scenarios.
Applied Responsive Devices questions how to enhance the organisation and transfer of architectural knowledge by activating a strong interaction between analogue and digital modelling. It analyses the different possible applications of a model (to demonstrate, to analyse, to discover) and the properties that it should embrace (robustness, repeatability, resemblance) in order to be efficient.

Applied Responsive Devices is conceived as an educational and professional decision aid tool giving assistance to the decision-maker to fix the priorities related to a formal, functional, technological or engineering problem.

The project Applied Responsive Devices has been finalised to achieve the following tasks:

- Support architectural reasoning through time-based simulations.
- Develop and refine research tools through computational methodologies.
- Define a strategy that allows easy tracking of errors.
- Provide a conceptual and instrumental platform and a service to the scientific, architecture and engineering community.
- Contribute to the science of learning by providing an innovative methodology.

From a methodological point of view, the project makes use of developments in other scientific fields (for example, research developed by John Holland of the Santa Fe Institute (Holland, 1992)). In fact, some architectural problems can be managed with a classifier system, consisting of a set of rules, each of which performs particular actions every time its conditions are satisfied by a specific informational attribute. Applied Responsive Device innovation also includes the way in which quantitative and qualitative parameters (i.e. social, physical, sensorial, cultural and economic) are aggregated in order to emphasise the concept of formal adaptation.
The aim is to embed sets of constraints within the modelling process that affect the decision-making of the designer.
Such an approach leads to architectural students' and researchers' heightened control of an increasing level of complexity in the design, engineering and production processes.

The research Formal Modulation for Acoustic Performance starts from the projects 'Ceresiosaurus', 'Desailopontès' and 'Runninghami' : these are works by Pascal Amphoux (Contrepoint Urban projects, CRESSON) and Filippo Broggini (BlueOfficeArchitecture) and are co-based on an exploration of the problem in order to engineer a formal solution for highway bridge acoustic panels in response to a given set of requirements.
The researchers developed a morphodynamic design to (1) optimise noise reduction in the area surrounding the structure (2) provoke a perceptual experience for the drivers and for the habitants and (3) render possible new uses of the spaces in immediate proximity.

The original proposal consisted of a formal modulation based on acoustic performance obtained by means of manual interpolation between engineering data and acoustic tables.

The project Formal Modulation for Acoustic Performance was developed in collaboration between NSU and Cresson. The research carried out at the CRESSON laboratory focuses on the issues of environmental perception and on architectural and urban atmospheres. CRESSON advocates a qualitative and dynamic approach susceptible to facilitating or influencing design strategies and processes.

The real case study Formal Modulation for Acoustic Performance was conceived to verify the validity of the methodological hypothesis analysed in the Pilot Model Applied Responsive Devices. The goal was to evaluate which tools have the capabilities to respond to formal, managerial, structural problems arising in the architectural domain.

Precedents of the research Runninghami

Concept design of acoustic protections for motorways South-Loire [A47, Rhone - Loire]

Runninghami is part of the process 'Highway Design'of the DDE of the Loire. This is the project of a multidisciplinary team composed of architects, engineers, planners, and lighting and acoustics engineers placed under the direction of the architect Pascal Amphoux geographer.

The concept

Runninghami, a term fed by three references:

- A symbolic reference to the work of Christo, 'running fence', which began in the seventies a 42 km wall of painted fabric in the California landscape aiming to emphasise the folds,
- A reference to the technical and constructive Japanese art of folding and origami. Origami refers to the local industry of ribbon manufacture and metal. The landscape fold meets the principle of folded sheet metal and deploys a ribbon,
- A perceptive and dynamic reference to the choreographer Merce Cunningham, whose art of dance in space was transformed to the art of the dancing space. To the perception of movements of the highways in the landscape is added the perception of movement through the landscape.

The challenge

For the classic issue of the fight against noise, the researcher substituted a problem territorial requalification. The goal was to ensure that a screen can be used as another task beyond its primary function. The screens were not only supposed to carry the noise reduction but also to carry a user aesthetic quality. Screen task was to enable the users to provide new uses in the surrounding areas and make possible the urban development's on its shores. Two approaches with an iterative and complementary process have been defined to achieve the development of the project in the form of a design chart.

The territorial approach

Consisted of the collection of the 'stories' of four actors' types through which it is possible to read the territory:

- Road users (motorists). Design of 'on board paths' and 'mental maps' to analyse the perception in motion and representations of the territory.
- Road professionals (subdivision 'highway' of the DDE). Carrying out daily monitoring to capture the technical issues of implementation of the object,
- Responsible for the territory (politicians, technical services and residents' associations of the

town affected by the roadside path). Working with 'talks on map reading' or 'guided tours' to understand the issues of planning from the micro to the city scale.
- 'Experts' in the territory (professionals who piloted studies or projects on the territory). Working on a round table to take into account the territorial and urban projects under way.

Actors involved	Method of description	Object	Scale
Road users	24 ' mental maps ' and 6 ' board paths'	The landscape	The valley
Road professionals	9 interviews and or guided tours	The city	The towns
Subdivision 'highway' DDE	1 day survey on the site	The equipment	The shores
Experts	5 round tables	The context	The territory

Some characteristics of the territory born of three arguments underlying the concept design: roughness, laterality and meandering.

The typological approach

Consisted of working with three different logics referring to three scales:
- Typological continuity and discontinuity developed according to a morphogenetic principle affecting the landscape scale.
- At the local scale the relationship between the static perception of the coastal walker and the dynamic vision of the car drivers.
- Declination of the constructive types according to the topological context: the principle of construction, mode of production, assembly, anchor and / or maintenance throughout the scale of the project.

The design chart

The design chart renders and synthesises the two previous approaches. The chart enunciates the morphogenetic invariants, the fold, and explores all the possibilities of formal variations that the device can deploy. The fold has to adapt to most contextual situations: different acoustic adaptation to the environment, topological forms responding to the shore or the surroundings elements, and perception 'symbols' of the motorist in motion.

In its description of the various operations allowed by the system, the chart defines and unfolds both the technical studies and practical recommendations to move from concept to completion. Materials and manufacturing processes, acoustic performances, structure and static issues, light design and costs estimates provide the basis from which to develop preliminary drafts in situ.

I. NSU contribution

NSU researchers worked on a reverse design logic: the size and shape of each panel are determined by the necessity to respect the constraints deriving from the function inserted in the 3d model. In the project Formal Modulation for Acoustic Performances[2] acoustic and perceptive

Figure 1
Section on the road A 47.
Image on courtesy of Cresson
and BlueOffice

Figure 2
The design chart : the fold. Image on
courtesy of Cresson and BlueOffice

Figure 3
Description of the perception in movement.
Image on courtesy of Cresson and BlueOffice

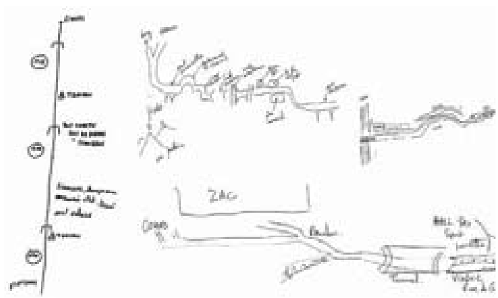

Figure 4
Mental maps.
Image on courtesy of Cresson
and BlueOffice

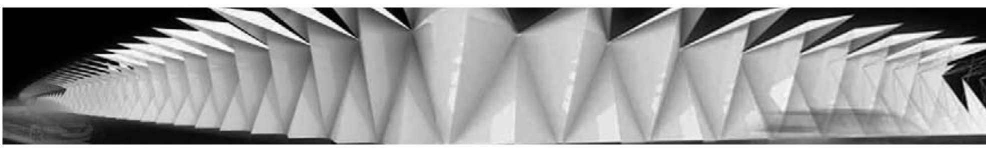

Figure 5
The fold and the plastic principle. Image on courtesy of Cresson and BlueOffice

constraints were integrated in the digital modelling process. At any moment, basic relationships required by the empirical acoustic evidence are satisfied.

The project Formal Modulation for Acoustic Constraints was developed in collaboration with Cresson researchers following a chronological sequence of phases.

i. Propedeutical preparation: collection of data and survey.
Researchers used data (survey of the site and acoustic requirements) provided by Cresson and Blue Office Architecture.
ii. Definition of the predominant factors influencing the formal response to acoustic requirements of the site.
iii. Subdivision of the problem into a system of elementary units: attributes and building blocks.
iv. Fragmentation of physical and conceptual problems into attributes and building blocks. Reduction of the problem into a set of elementary units.
All partners defined a set of technical, acoustic, economic and social factors influencing the different elements' formal requirements. They established a checklist that the designer and students used to collect information.
There was analysis of the conditions in which formal and performative requirements and performances can be represented through sets of numeric data.
v. Expression of architectural principles through a set of dynamical relations: articulation of the project in a set of relations and translation of t input in abstract symbolic language.
vi. Guidelines relating acoustic performance and other factors..
Definition of formal aspects and acoustic criteria. On the basis of the analysed results of the task was to define the parameters and the rules describing the formal response of the different panels on the basis of sound/acoustic requirements.
vii. Extension of data model and method implementation.
(The algorithms of the model were incorporated into a software application). Initial data resulting from the survey were complemented with additional data sources according to the simulation model requirements. The entire database was defined to identify and develop correlations between the acoustic requirements, the influencing factors and the formal attributes of the solution.
viii. Method Implementation
The algorithms of the model were implemented into a software application and delivered to users.
ix. Development of a user-friendly interface.

II. Description of parametric systems

The Project Runningham

The parametric device operating in the project Runninghami is the system of equations that

generates the geometry of the structure. It is finalised to satisfy both the attenuation requirements. It respects the needs of the surrounding habitat for acoustic protection as part of the structural requirements. The folding principle is the generator of the entire system.
In the initial project the principle was defined on the basis of a set of triangular faces that generate the overall assembly of the components (faces K and N). In-between those faces are located two other triangular faces (faces L and M). On the top of those last faces is situated the roof (faces O and P). Each one of those elements contributes structurally and acoustically to the behaviour of the overall system.
Each triangular surface is defined on the basis of a set of points called 0, 1, 2, 3, 4, 5 and 6. The surface generation is based on the definition of the points in relation to their relative coordinates (x', y', z') and in relation to their relative position to the absolute reference (x, y, z) and to the road coordinates (u, v, w). The points 0, 1, 2 are located on the horizontal plan (the ground relative to the system x', y', z'), and defined on the basis of an 'S' module. The variable 'S' affects most of the other variables.
The height H is expressed responding to S. The value B (that for reasons of simplicity has been considered as constant) could change in relation to 'S'.
The vertical panel rotation also changes in response to 'S'.
The horizontal rotation ß (representing the road inclination) could also change in accordance with 'S'.
If a change of reference is applied between the road u, v, w axes and axes x, y, z of the absolute reference, the system adjusts itself to the form of the road. This change is described by the vector r (t). The vector r (t) describes a curve that could fit any space.

Variation of the 'S' value

In the first phase researchers chose to generate value by dividing the S axis with simple functions. It was possible in this way to achieve connection with the shape of the folds and, the structural behaviour, and to broadcast sound and modulation of light and shades.
In a second step, researchers implemented more complex functions to accentuate the motorway sequences by adapting its local 'speed'.. By simple winding curves at variable periods, the "S" value could mark sequences of events functions of the highway (slopes, curves, interruptions of the hard shoulder, exits,).
Those variations could even be refined by more complex functions. In this last case the results produced were more random

NSU parametric system

NSU researchers worked on reverse logic: the size and shape of each panel were defined by the set of dynamical relations deriving from the introduction of an empirical acoustic function into the 3d model. The geometrical variables were connected by a function contributing to the definition of the shape of each panel in the various areas of the site. The project unfolded sets of formal solutions through rule-based modelling and programming.
In a first phase NSU researchers developed the basic tool by connecting the noise attenuation

Method Proposed in the Pilot Model: Applied Responsive Device

Input
- 1A Goal Definition
- 1B Enunciation of Relevant External Input and Condition Operating in the System (technical, programmatic, formal)

Abstract Brain
- 2A Translation of Relevant External Input into Numerical Data or Numerical Attributes
- 2B Enunciation of the Technical Primary Rules
- 2C Enunciation of the Designer's Secondary Rules
- 2D Translation in Symbolic Language of the Basic Rules and Constraints Connecting the Different Attributes
- 2E Organization of the Rules into a Hierarchical System
- 2F Connection Between the Numerical Data and Rules to the Geometric Realization (geometric variation of the model: scale, thickness, density, orientation, rotation, etc.)
- 2G Definition of the Limits and Conditions of the System

Physical Resolver
- 3A Identify Tectonic Reaction to Specific Conditions (specific materials, etc.)
- 3B Evaluation of Solutions as Applied to the Building System
- 3C Definition of the Limits and Conditions of the System

Figure 8
Logical model of the APPLIED Responsive Devices: definition interaction between the analogical and digital dimensions of architecture. Image on courtesy of NSU.

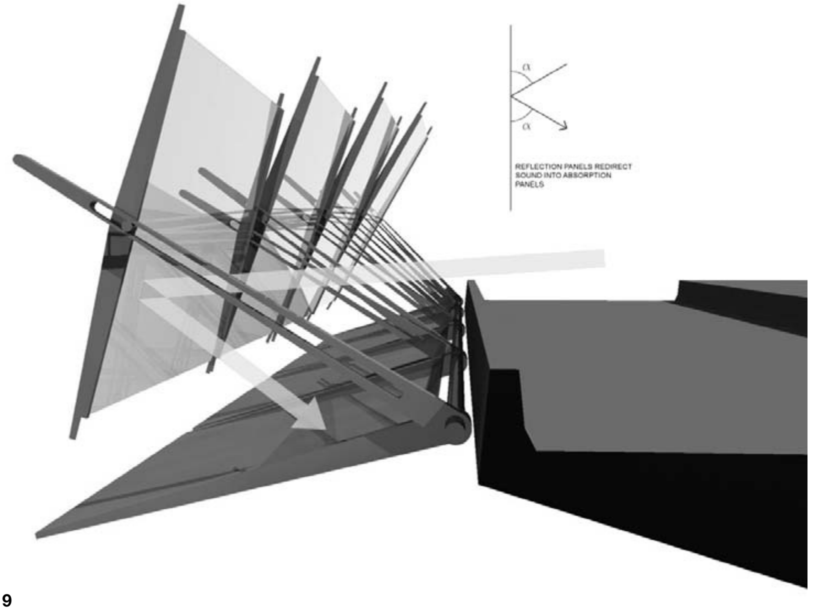

Figure 9
The system of reflective and absorbing panels connecting acoustic performance and relevant views of the landscape. Image on courtesy of NSU.

desired at a specific point to the distance and the rotation of the sound source. All those parameters were linked to the position of the point to be isolated. Through implementation of the process of Applied Responsive Device the input of the project was transformed into numerical attributes. The formula was therefore linking the desired attenuation to the distance of the source point, the height and rotation of the panels and their relative position.

Once the set of relations was defined, researchers developed a tool allowing connection of the 3d model to the rules of the system. This first device was an abstract apparatus in which the number of variables (height, rotation, number and position of the panel) allowed the definition of many possible architectural solutions.
On a second occasion the researchers engaged with the problem of different formal solutions or physical resolver embedding not only the acoustic constraints but also other parameters deriving from the qualitative and perceptive dimension of the design. Researchers developed three formal proposals performing in different ways in accordance with their design intentionality.

In the first proposal researchers added to the acoustic constraints a rule connecting the visual criteria. The goal was to allow to the driver to perceive some specific point of interest (the village, the lake or the church) from the road. In this case the system was incorporating the rule that if in the visual axes of the drivers there was an interesting view, the panel would be a transparent reflective panel bouncing the sound on to another absorbing panel. The system was growing and rotating in order to respect the constraints defined by the empirical formula provided by Cresson. The movement of the two types of panel (reflecting and absorbing) were linked to the mechanical behaviour of the device designed by the researchers. The movements in the space were not only responding to the acoustic constraints but also to the perceptive and technological ones.

Another group of researchers developed a structure in which the rhythm of the panel was defined by the velocity that the drivers were supposed to maintain on the road. The number and the rhythm of the acoustic panels affect the driver's view. If the car goes above a specific speed the acoustic panels will perform as a unique visual barrier. In this second case the digital model is connected to the empirical formula (in this case modulating the height of the single panels and not the rotation), to the speed that the driver should respect in a determined area and to the number of panels present per linear metre.

The project investigated the possibilities that that were opened up by the modulation between the combinatory potentialities of the different performance criteria with the designer's intentionality. The project challenged and enhanced architecture's capacity to respond to specific acoustic and environmental requirements with its adaptable physicality.

From an epistemological perspective the tool operates as a heuristic device aiming to challenge the boundary between the Measurable and Non-measurable dimensions in architecture.

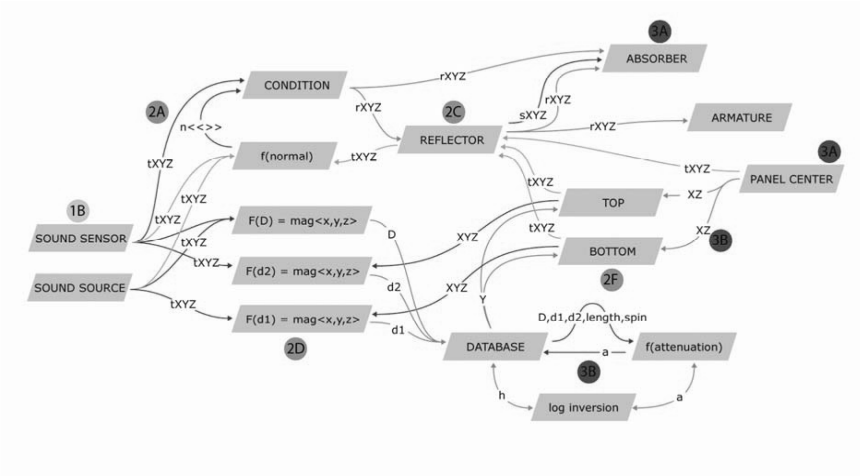

Figure 10
First NSU proposal, connecting the view with the transparency and sound reflectivity of the panels. The logical model of the Applied Responsive Devices: definition interaction between the analogical and digital dimensions of architecture. Image on courtesy of NSU.

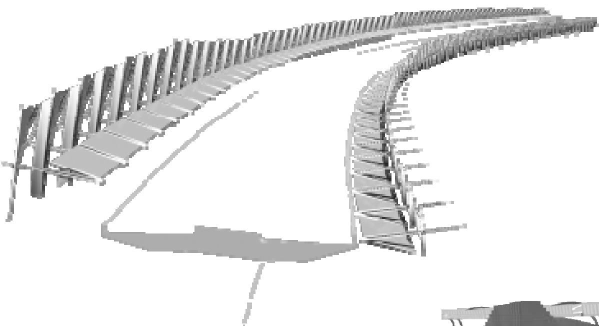

Figure 11
Various panels responding on the site conditions.
Image on courtesy of NSU.

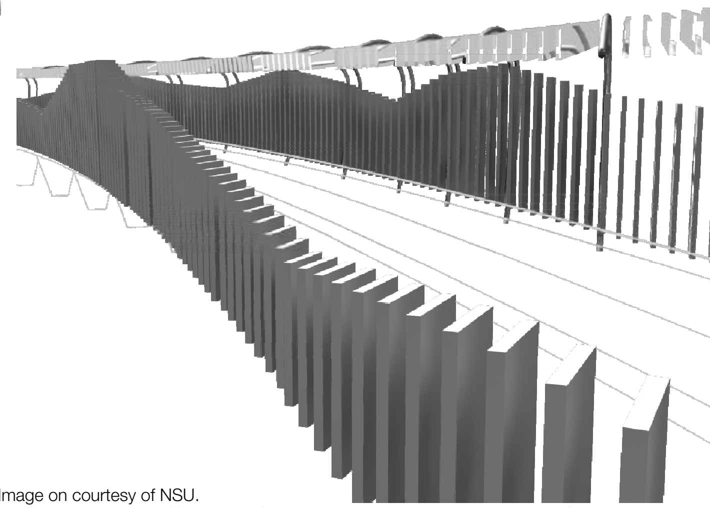

Figure 12
The change of frequence defined on the drivers speed. Image on courtesy of NSU.

Composition of the team

General design and coordination of the team: Pascal Amphoux, Counterpoint, Urban Projects (Lausanne, Switzerland). Architecture and landscape.

Social Economy and territorial policy: Nicolas Tixier, Jean-Michel Roux, Bazar Urbain collective interdisciplinary (Grenoble).

Design formal, structural design: Filippo Broggini, architecture and civil engineering, BlueOffice Architecture (Bellinzona, Switzerland).

Acoustics and Informatics: Pierre-Yves Nadeau, Council Engineering Acoustics (Marseilles). Acoustic design, simulation, mapping sound.

Lighting design, lighting and security: Laurent Fachard, Éclairagistes Associates (Lyon). Ergonomics and visual lighting,

NSU experimental group, digital implementation, development of the technique Applied Responsive Devices, development of other formal proposals responding to the same logic: Caterina Tiazzoldi, Nicolas Tixier, Chris Whitelaw with Peter Albertson, Aaron Bowen, Sang Hoon Youm and K. Chan zoh.

Notes

1 Caterina Tiazzoldi, *Automatismi o Strumenti Non Lineari di Progettazione*, PhD thesis, Politecnico di Torino ,May 2006.

2 This project has been made possible by the support of the DIPRADI of the Politecnico di Torino,, Ecole Architecture de Grenoble, ISI Foundation, Laboratoire Cresson and NSU at GSAPP, Columbia University.


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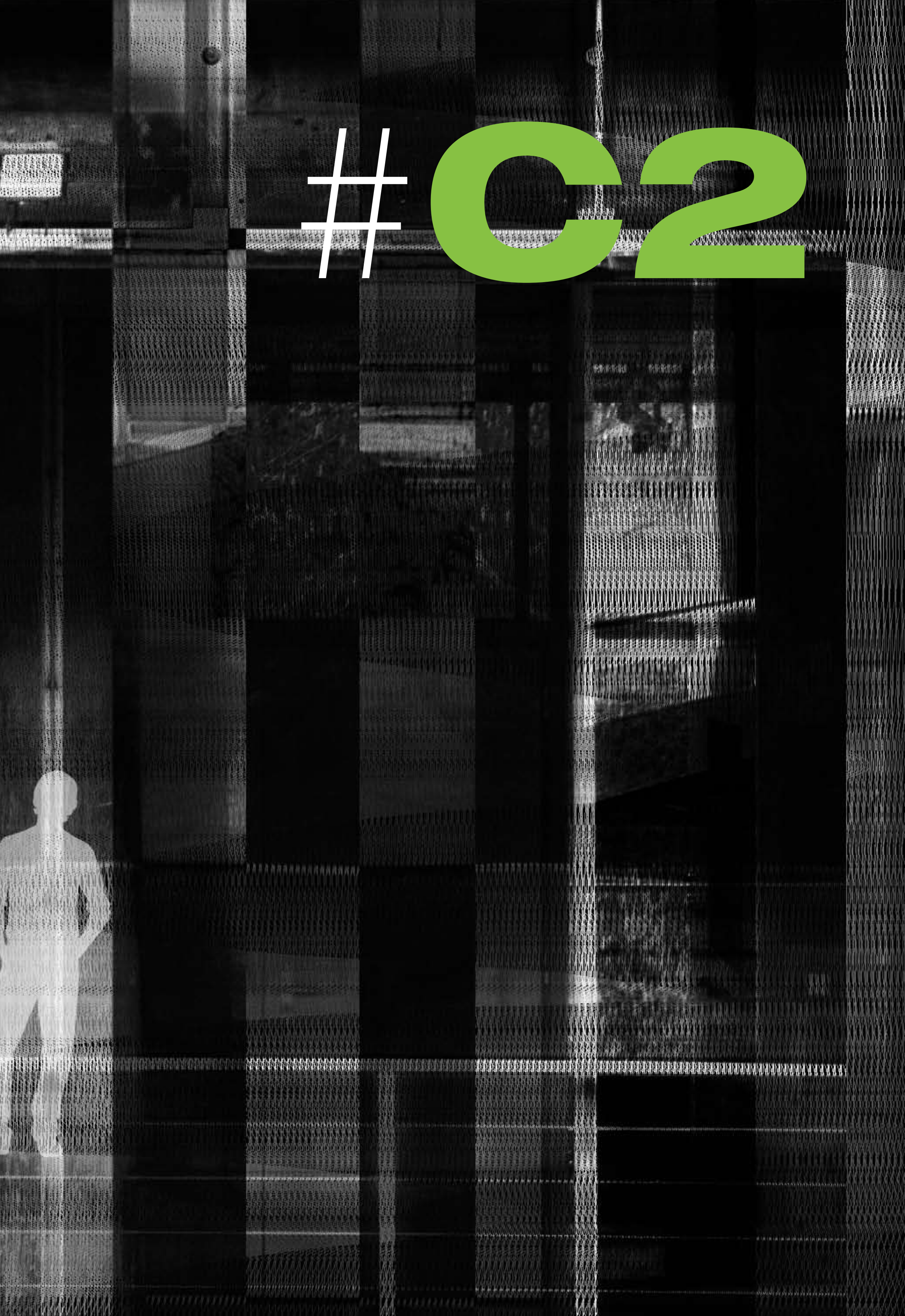
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