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FROM DIMENSIONAL TO NON-DIMENSIONAL SIMPLE STATES: A COMPUTATIONAL DESIGN METHOD FOR EARLY STAGES OF DESIGN

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Abstract

The work presented in this paper was conducted during the research for finding a computational method for use in the automated design for hospital buildings. The method uses a heuristic approach and uses architectural shapes (or form) as a primary generator in the synthesis of form. This novel approach which introduces two design worlds – the dimensional and non-dimensional – offers a new possibility for incorporating multiple computational techniques to help computational design. In this paper, we introduce the 'simple states' - primitive shapes that exist in both dimensional a non-dimensional world and are proposed for use as instances in form generation of complex rectangular shapes in hierarchic design strategies.

Keywords: dimensional, non-dimensional, shape primitives, simple states, instances

1. Introduction

Architecture is often seen as a process or discourse towards finding a final product based on the interplay between activities (function) and volumes or massing (form). The conventional methods of solving the final product are different both in structure and content and mainly follow two main general approaches: the top-down approach and the bottom-up approach. The first approach engages reductive techniques, beginning with an overall schematic sketch (predominantly with massing) proceeding with a gradual refinement until a final solution is accepted by the designer. The second approach involves constructive techniques that start by merging certain units or sub-systems in building a final and complex system based on predefined rules and constraints.

In analogy with these two conventional approaches, studies, and research for creating computational methods in architecture within the science of architecture have been conducted using both conventional approaches. Even though most of these methods try to solve layout configurations based on topological relationships for a given specific program of spaces (a bottom-up approach) (Saliu, Maliqari, & Memedi Usejni, 2015), there are studies and researches done that try to create a computational design world based on shapes and forms (massing) that incorporate and mimic the reductive approaches 'used conventionally by experienced designers' (Mitchell, Ligett, & Tan, 1989). These computational techniques are based on finding formal aspects of problem-solving (computationally efficient) and do not necessarily imply the use of computer (Terzidis, 2006) although their validity and evaluation is built-up upon using computer systems.

Our aim in this paper is to present a part of larger research conducted in finding a theoretical mathematical model of shapes that would be able to support a computational design in the initial stages of hospital design. Our discourse here would focus only on the form generation technique as part of the research which supports reductive techniques in the overall schemata.

Most architects, especially experienced ones, in each program of spaces or building programs, start their thinking with massing within a given site. The architect starts his/her thinking from geometrical properties of the site firstly, and by manipulating shapes and three-dimensional forms to fit site regulations and his/her personal subjective expectations for the architectural form and shape configuration. Akin & Hoda (2004) through protocol analysis confirm that massing is 'the primary subset of the early stages of built form creation' and that regulating elements are used by designers for managing and manipulating with massing. These elements included regulating lines, alignment lines, symmetry, mass boundaries, etc., (Figure 1) and are part of a strategy and mechanisms that designers use throughout their architectural discourse (Akin & Hoda, 2004).

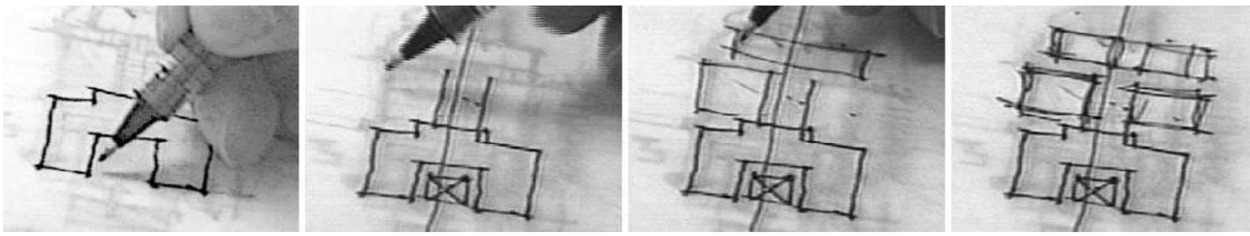


Figure 19. The process of creating massing elements (source: (Akin & Hoda, 2004))

It is vital to emphasize at this moment the importance of boundary lines as a prerequisite for massing (in terms of three-dimensional volumes). As Figure 1 shows, to keep their expectations for the overall form or shape, architects use complementary regulating elements since they help them keep order of their desired and imagined shape. In this way, they proceed gradually in breaking down the overall structure of a certain space program simultaneously. Thus, 'design specifications and relations that need to be satisfied in the design solution are defined' (Akin & Hoda, 2004).

By observing Akins and Hoda (2004) research, we can instantly speculate that one of the most important tasks of the designer during this stage is finding the overall shape of the building in terms of contour lines of the building, although the design process includes more than just that (he structures main form, function, process, functional zones, flows, and circulation, by defining the contour lines of the building). Architects do so because they already have information and knowledge of that kind of building type.

2. Contour lines as primary generator

The importance of contours in the definition of the overall form of the building and the initial stages of design is highlighted also in the generic representations proposed by Achten (1997). By identifying generic representations and graphic units in a building type, we can encode declarative and procedural knowledge of that building type (Achten, 1997). Achten identifies three main themes that group similar generic representations: shape, structure, and systems. The shape is the first theme, and it is made of contours (simple, combined, or complementary) and simple contour is the first graphic representation that contributes to the shape theme (Achten, 1997). Simple contour as a generic representation represents a closed shape that defines properties – mainly topological - such as articulation, perimeter, number of edges, surface, etc.

Since our primary motivation was the designing of effective computational tools that would support design in the initial stages of design, defining contour lines or overall shape as a primary generator of form was fundamental. This would imply that in the 'design world' (Mitchell, 1990) we try to define, contour lines or boundary line of massing would instantiate our design strategy (**Figure 20**).

At present, as contour lines represent a building shape, we would refer to it only as a shape in the discussion below. In order to instantiate a certain shape, here we can raise a very important question about this shape: is the shape dimensionally exact during this phase of design, and could it act as an instance?

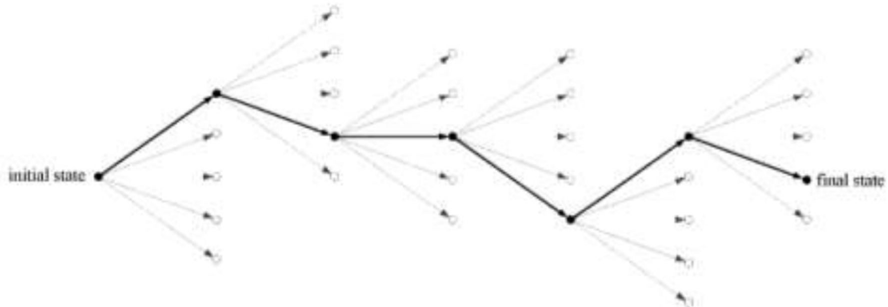


Figure 20. State-action tree for a design world (source: (Mitchell, 1990))

3. Non-dimensionality of shape

The shape represents a built form of identity. Akin and Hoda (2004) observed that elements such as ‘points of intersection, centers of rotation, lines and planes of the intersection, axes of rotation, axes of symmetry, alignment, diagonal proportion lines, and bounding lines, planes and volumes’ (Akin & Hoda, 2004) were the main massing strategies and mechanism of maintaining order during the design process. Architectural massing in this stage is rough since the architect’s ability to define exact dimensional parameters is impossible (dimensional properties represent a quality of the final product, i.e. we obtain final dimensions of the product in the final stages of design). He/she tends to keep order based on the relationship between different parts of the form and context. Operators like equal to, the ratio between, rhythms, symmetry, rotation, compactness, articulation, flexure, opened to, close to, skeletal, non-skeletal to name a few are the main tools he uses to build up his massing. All these operators represent non-dimensional parameters. This implicates that massing represents a relational shape – morphological relations rather than a dimensional one.

Let’s discuss this from a different perspective and in the opposite corner of the design process by examining the final product in form of its shape. In the Figure 3 are presented two identical shapes of a built form. In the foreground we perceive these shapes as identical because the relationship between their constituent components and elements is identical, i.e. they have the same articulation, same symmetry, and they are both skeletal, and so on. This is our first impression of these shapes – they are similar and identical even though their size differs if we refer to their scalars below.

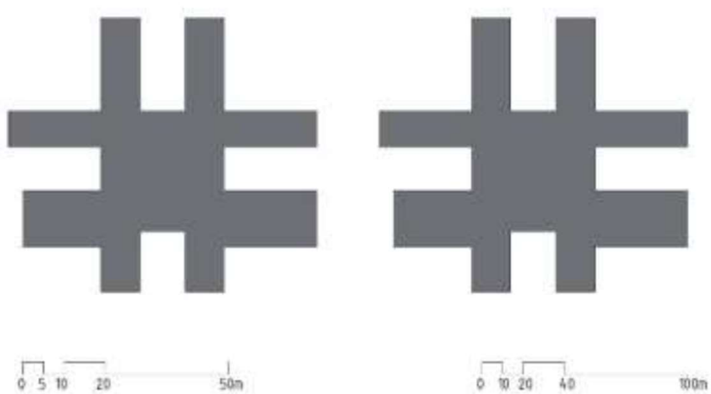


Figure 21. Identical shapes, different in size (source: (Saliu, 2018))

So, at both ends of the design process, shapes are more relational rather than dimensional. The dimensional aspect is closely linked and imposed by the space requirements of a building program that designers try to solve in a later stage of the design process. Consequently, keeping relational aspects of shapes establishes a key factor in the design world that we try to create. Accordingly, since dimensionality is a transformation that is established in later stages of design and in accordance with the initial requirements themselves, we can proceed with our strategy from a non-dimensional world because all the above-mentioned operators would be present without exception.

Likewise, non-dimensionality is presented in Steadman's 'archetypal building' whereas Steadman states 'all dimensions are to be conceived as being parameterized' (Steadman, 2001; Steadman, 2010; Steadman, 2014). His technique of generating individual forms by applying a series of transformations to a single generic nondimensional form (archetypal form) is similar in terms of the approach undertaken in this discourse. Steadman's archetypal building is far from application in real-world built forms because it is based on a particular binary encoding (in rows and columns on a single, four, or nine court archetypal building) which produces regular shapes in terms of complexity. All derived forms fit the archetypal building, thus their ability to perform as real potential candidates for a computational design method is limited. Therefore, other steps were followed in this research for creating a non-dimensional construct. Further decomposition of shapes was crucial to identify their primitives and their properties.

4. 'Simple states' as instances

The initial shape of massing constitutes the primary form of any architectural idea and consists of multiple combined lines that form a closed planar shape. This shape determines the topological qualities of the form, perimeter, surface area, dimensions, and its constituent simple shapes. Breaking down the shape even further would bring out its primitives. So each shape: a) consists of combined primary and simple shapes that are arranged accordingly; b) each of these simple shapes is characterized by a certain 'state' in relation to other constituent simple shapes and c) the combination of these simple shapes determines the logical structure (logical construct) of each form and allows the possibility of bi-directional development during the design processes (descriptive-analytical-synthetic and vice versa).

We have identified five unique '*simple states*' (**Figure 22**) that constitute every possible complex rectangular shape that humans can create. Since the aim of this study are articulated and complex shapes, i.e. shapes constructed of multiple simple contours, self-existing or isolated simple shapes will not be considered as 'simple states'.

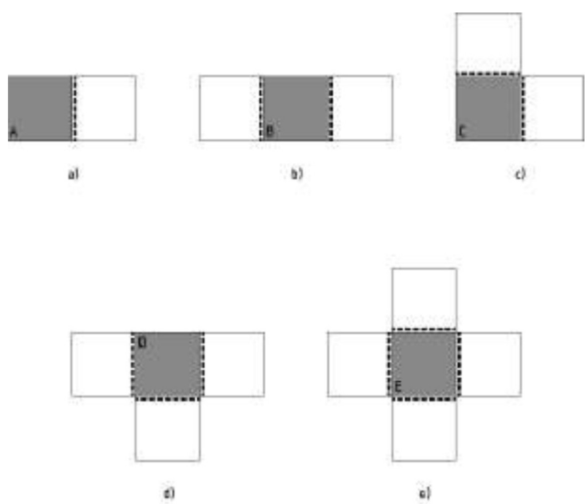


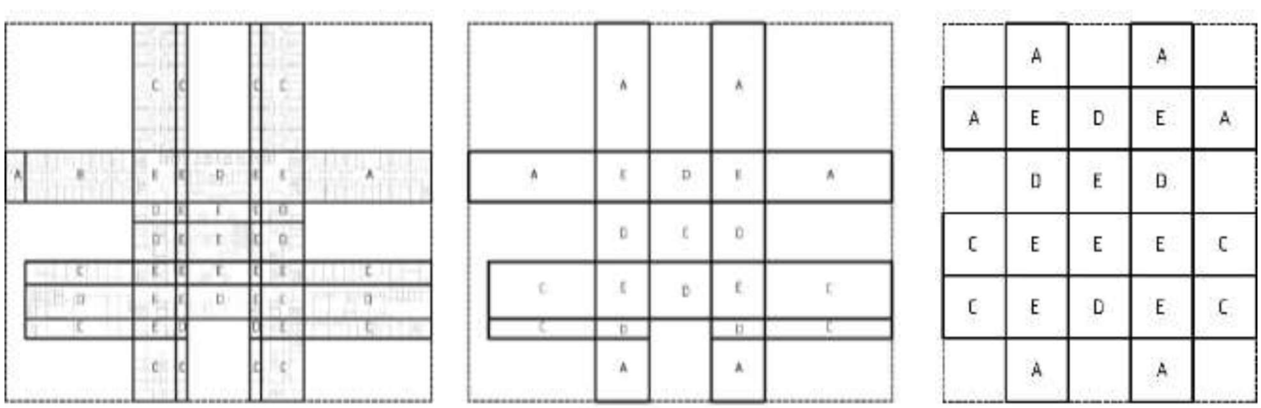
Figure 22. 'Simple states' of shapes (source: (Saliu, 2018))

The first state (A) represents a simple shape that is attached just to one side with another shape. This means that the other three sides of this shape are opened and day-lit (Figure 4-a). The second (B) and the third (C) states of simple shapes are free and opened by two sides and attached with other shapes by the other two sides accordingly - linearly attached for state B and in angle for state C (Figure 4-b-c). The fourth state represents a shape that is opened and day-lit only on one side while the other three sides are attached to other shapes. And, finally, the fifth state, represents a simple shape that is attached by all sides with other simple shapes (Figure 4-d-e).

These ‘states’ are direct interpretations of shapes and form and they convey logical information about the shape such as: direction, connection-relations, and illumination. These qualities are both dimensional and non-dimensional so that they can be preserved also as dimensional and non-dimensional structures.

To distinguish simple states in a certain existing shape or initial massing shape, a slicing plane in each node of articulation needs to be created bi-directionally for all levels together. In this fashion, we can obtain rectangular dimensional simple states for analysis in each shape or floor plan for a built form on one hand (Figure 5-b) and non-dimensional construct for the same shape on another hand.

The non-dimensional construct (design world) is created by converting all dimensional simple states (Figure 5-b) into a single equal unit and by keeping intact their relational properties. This would create ‘unit states’ or non-dimensional simple states (Figure 5-c). By doing so, we create a mathematical model that excludes dimensional parameters and includes all relational properties of the dimensional construct, and beyond this, keeps the abstract aspect of the form. This would help in further progress and certain conclusions could be derived from analyzing existing building types. These conclusions can help in the synthesis of an initial massing shape for the same building type afterward.



Simple states in a floor-plan of a built form

Simplification of dimensional simple states

Non-dimensional simple states of a built form

Figure 23. 'Simple states' identified in a case study - Building 19 - Appendix A (source: (Saliu, 2018)

The process of using ‘*simple states*’ for analysis of actual built forms and shapes is straightforward process and very simple. The steps are as simple as follows: for all the floorplans at once all the articulation nodes are taken out and identified. Slicing planes in both directions (x and y) are placed in each node of articulation and as a result an outcome of multiple rectangles of different proportions is obtained **Error! Reference source not found.**-a). These rectangles represent the dimensional ‘*simple states’*.

On the other hand, the process of synthesis using simple states can follow two different approaches for instantiating the contour line or the desired massing shape. The first approach involves a direct involvement of a human, i.e. he needs to draw the desired shape directly on the workspace of the system and the second approach involves computational methods for generating automated shapes. In both cases, the result will end up generating just a rough shape which then produces rough simple states and then a non-dimensional construct of simple states for further development.

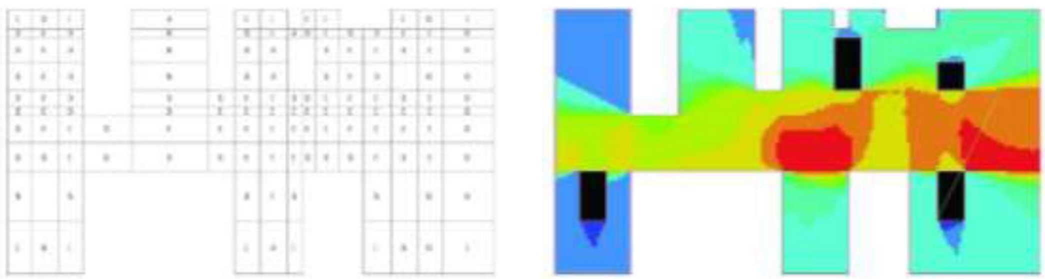
In this way we can involve in both directions of design processes the proposed ‘*simple states*’ – for analysis and for synthesis. In all building types, analysis acts as a precursor of synthesis.

5. Evaluation of 'simple states'

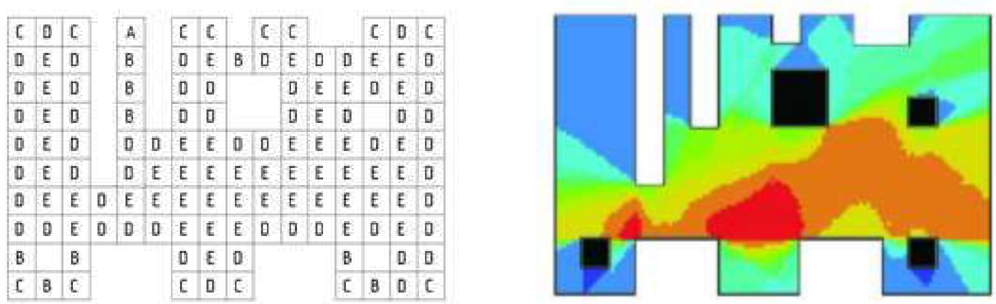
We have established two design constructs for an architectural shape. The dimensional construct is made of *dimensional simple states* and non-dimensional construct form *unit simple states*. As a result, these simple states act as mediators between these two constructs.

In this stage of progress, an evaluation of the non-dimensional construct was conducted to check whether the main relational properties of the shapes are maintained. Regulating lines, the axis of symmetry, articulation, adjacency, and similar properties implicitly are present since the non-dimensional construct is built upon exclusion of only dimensional aspects of the same simple states' arrangements.

Further evaluation was undertaken in terms of shaping visual integration from Space Syntax. Twenty built forms of hospital buildings were chosen for this purpose and their respective shapes were drawn (See Appendix A). All simple states for dimensional shapes were identified and consequently, non-dimensional constructs were created. For both dimensional and non-dimensional constructs, only contour lines were preserved and their respective visual integrations were analyzed (Figure 6.a-d).



a) Dimensional simple states of a built form   Global integration of dimensional shape



Non-dimensional simple states of a built form   Global integration of non-dimensional shape

Figure 24. Evaluation of non-dimensional simple states in terms of global integration (source: authors)

The results (see Appendix B) indicated that even the position of most integrated parts of dimensional shapes, in most of the case studies, was transferred in non-dimensional constructs. This showed that the 'simple states' were reliable and consistent features for further explorations and additional steps into the building and defining their properties as such was conducted subsequently. Axiomatization of 'simple states'

5.1 Dominance of simple states

Since *simple states* have relational properties and they are part of a system that has qualities, we observed some dominations of certain simple states over the others in terms of their day-lit qualities. Simple states A and B carry higher quality in comparison with the other three states. Thus, these two states directly affected the internal solution of simple states C, D and E, i.e. the flow of information is forwarded from dominant states (A and B) to dominated states (C, D and E) (**Figure 25**).

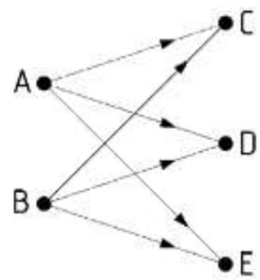


Figure 25. Dominance and flow of information between simple states (source: (Saliu, 2018))

In computational terms, this meant that dominant states could be directly solved according to their cross-sectional depth while the dominated states should be incorporated within a search algorithm for further development.

5.2 The logic of union

Simple states are proposed to support complex rectangular shapes and usually, they can be repeated depending on the complexity of the overall shape. The complex form or shape is a system that contains multiple *simple states*. During the study of many hypothetical shape scenarios, it was perceived that a certain degree of levels can exist between dominant states and the dominated states. These levels acknowledged the existence of certain patterns of *simple states* that could be merged and act as a single simple state – with no impact on a system breakdown. The union of these state patterns would considerably impact a later stage in the search space, thus reducing time-consuming calculations and combinations that would require the computer system. These patterns are listed as:

First level pattern - the union of first and similar dominant *simple states* (A and B) leads again in dominant states;

A . . . A ▻ **A**
B . . . B ▻ **B**
A A . . B ▻ **A**

Second level pattern - the union of two similar dominated states leads to dominant states;

0 C C **0** ▻ **A**
0 D D **0** ▻ **B**

Third level pattern - the union of two different dominated states leads to dominant states

0 D C **0** ▻ **B**

Fourth level pattern - the union of three different dominated states leads to dominant states

0 C D C **0** ▻ **A**
0 D E D **0** ▻ **B**
0 C E D **0** ▻ **B**

Fifth level pattern – the union of multiple different states leads to dominant states

0 C D . D C **0** ▻ **A**
0 D E . E D **0** ▻ **B**

These pattern levels can be encoded within the mathematical model and adjusted whether manually or automatically by an algorithm (note: number zero defines the outside part – environment).

Conclusion

The proposed *simple states* can exist in both dimensional and non-dimensional worlds. This will enable the development of a prototype system that will encode declarative knowledge separately. This will allow the creation of two search spaces within the overall design space. Logical operators such as regulating lines, adjacency, and orientation can be encoded in a non-dimensional search space and dimensional transformations and parameters in the dimensional one. In contrast of what most of what most of computer-aided design processes do by solving and composing forms at once, this approach allows a gradual step-by-step refinement in a hierarchical manner and separately.

On a methodological level, this research confirms that *'simple states'* that contain logical and dimensional information could derive other supplemental information's by applying them on concrete built forms for certain building types and especially in hospital buildings as the main objective of the larger research conducted during these years. This information derived from analysis can be used later for the synthesis of architectural massing of the same building type. In this manner, each step of the process derives new supplemental information's for the upcoming steps of the process.

In conclusion:

- Simple states can help in the analysis and synthesis of architectural shapes and forms.
- They keep intact the topological, logical, and dimensional qualities of abstract forms.
- Simple states can contribute as instances since they exist both in the dimensional world and non-dimensional world.
- Simple states act as a mediator between the dimensional world and the non-dimensional one due to their ability to preserve logical and dimensional information of a built world.

Simple states contributed to the creation of the 'cuboids' – a new type of non-dimensional shape vocabulary that was used for the next stages of design (Saliu, 2018). In the research twenty unique 'cuboids' were identified which can contribute to the analysis of existing building shapes and in the synthesis of new shapes. This vocabulary of shapes is out of the scope of this paper, so they are not presented here. In this article, only an introduction of 'simple states' is presented.

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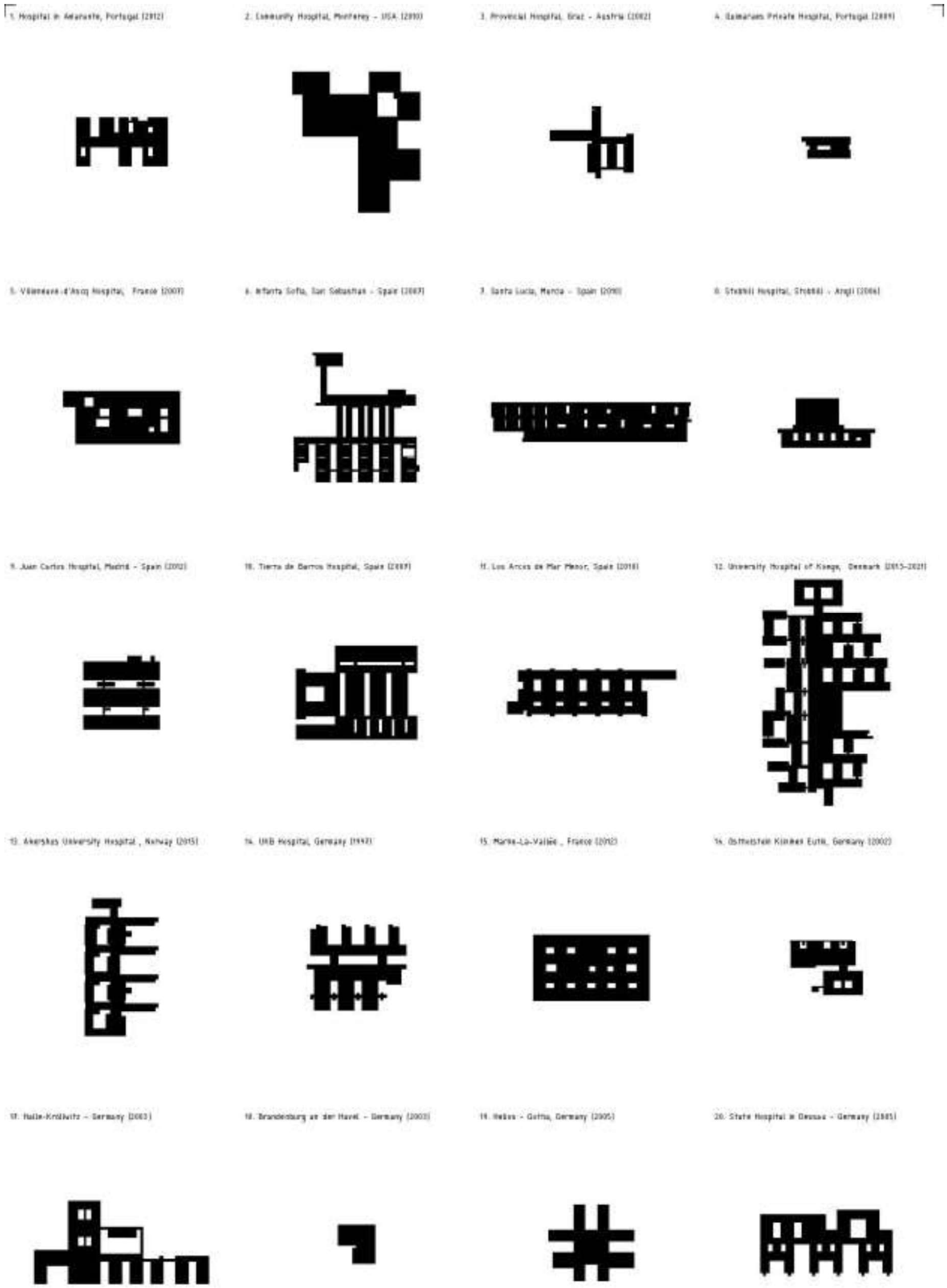
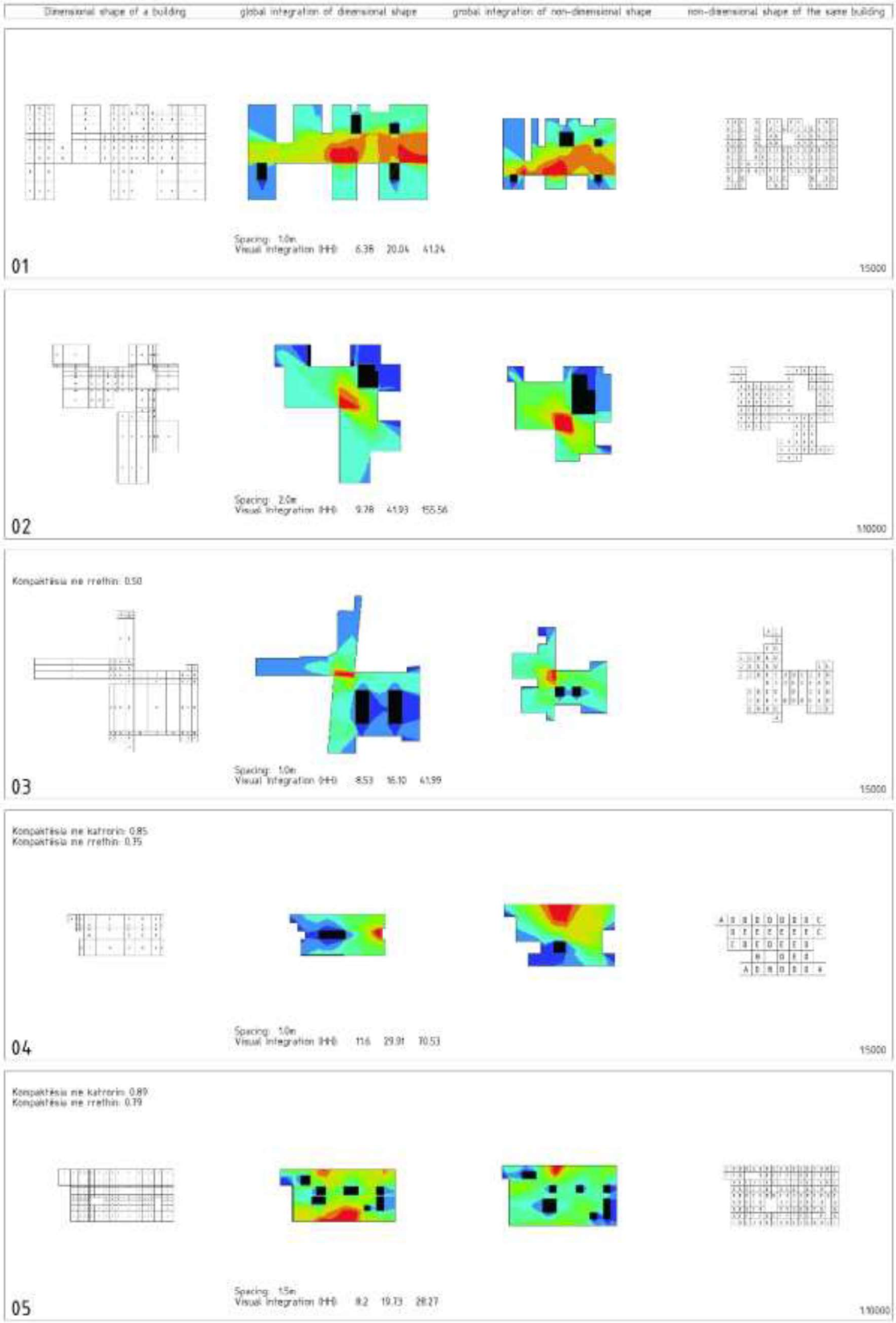
Appendix A

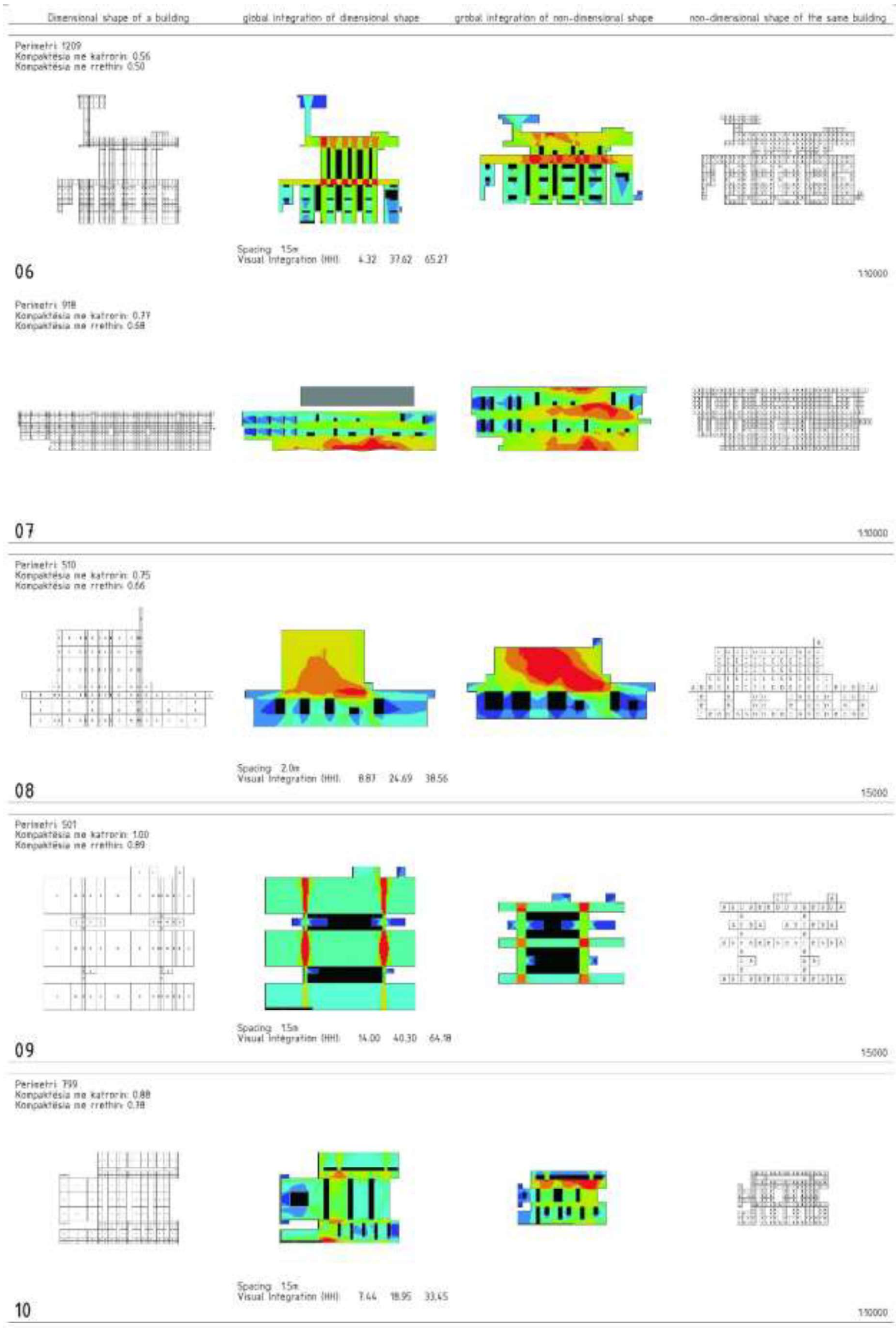
Case studies – hospitalbuilt forms

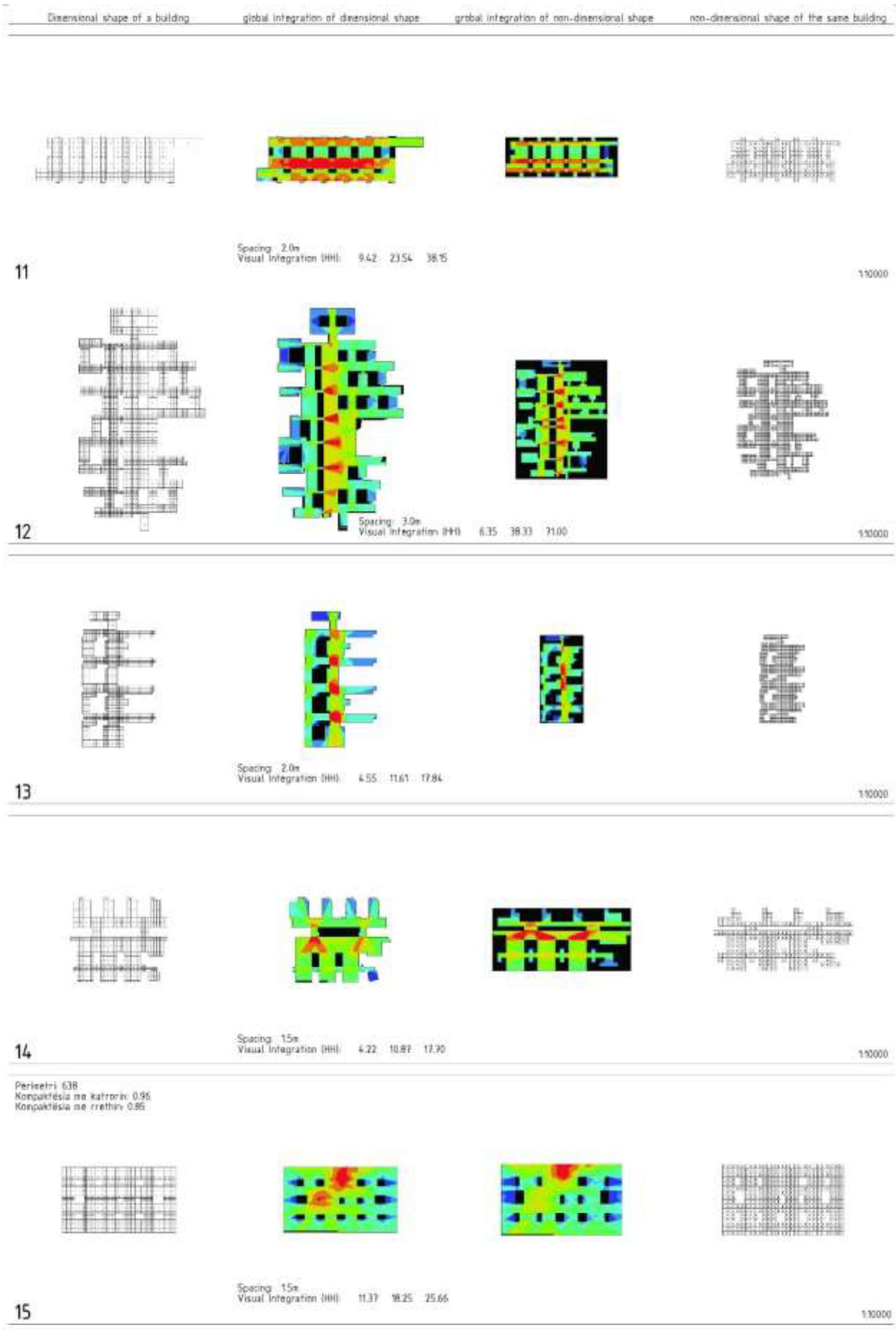


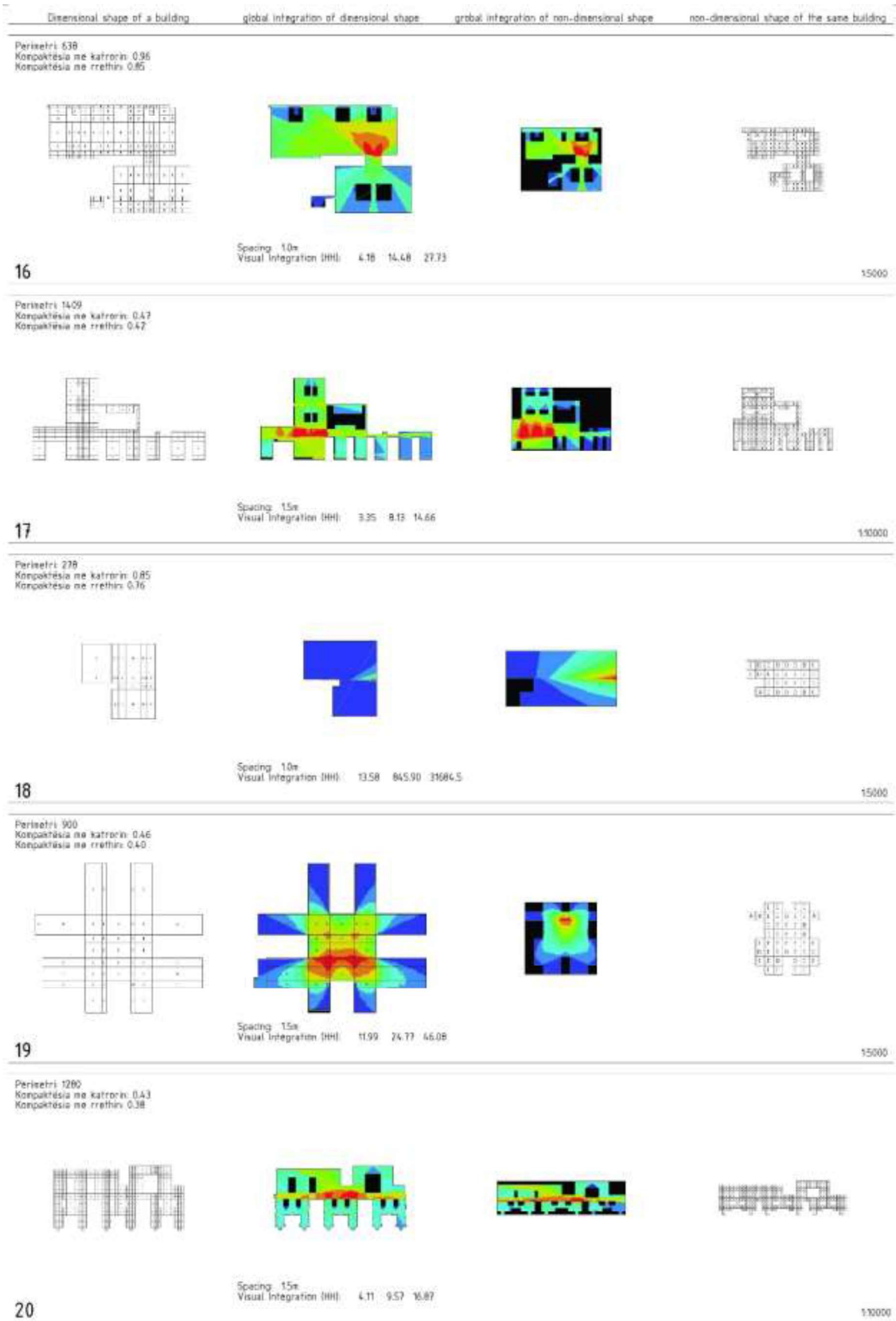
Appendix B

Simple states of dimensional built form, visual integration of dimensional shape of the built form, visual integration of non-dimensional shape of the built form and simple states in non-dimensional built form for comparison




Dimensional shape of a building
global integration of dimensional shape
global integration of non-dimensional shape
non-dimensional shape of the same building
Perimetri: 1209
Kompaktësia me katrorin: 0.56
Kompaktësia me rrethin: 0.50
Spacing: 1.5m
Visual Integration (HH): 4.32 37.62 65.27
06
1:10000
Perimetri: 918
Kompaktësia me katrorin: 0.77
Kompaktësia me rrethin: 0.58
07
1:10000
Perimetri: 510
Kompaktësia me katrorin: 0.75
Kompaktësia me rrethin: 0.66
Spacing: 2.0m
Visual Integration (HH): 8.87 24.69 38.56
08
1:5000
Perimetri: 501
Kompaktësia me katrorin: 1.00
Kompaktësia me rrethin: 0.89
Spacing: 1.5m
Visual Integration (HH): 14.00 40.30 64.18
09
1:5000
Perimetri: 799
Kompaktësia me katrorin: 0.88
Kompaktësia me rrethin: 0.78
Spacing: 1.5m
Visual Integration (HH): 7.44 18.95 33.45
10
1:10000


Dimensional shape of a building
global integration of dimensional shape
global integration of non-dimensional shape
non-dimensional shape of the same building
Spacing: 2.0m
Visual Integration (HH): 9.42 23.54 38.15
11
1:10000
Spacing: 3.0m
Visual Integration (HH): 6.35 38.33 71.00
12
1:10000
Spacing: 2.0m
Visual Integration (HH): 4.55 11.61 17.84
13
1:10000
Spacing: 1.5m
Visual Integration (HH): 4.22 10.87 17.30
14
1:10000
Perimetri: 638
Kompaktësia me katrorin: 0.96
Kompaktësia me rrethin: 0.85
Spacing: 1.5m
Visual Integration (HH): 11.37 18.25 25.66
15
1:10000


Dimensional shape of a building
global integration of dimensional shape
grobal integration of non-dimensional shape
non-dimensional shape of the same building
Perimetri 638
Kompaktësia me katrorin 0.96
Kompaktësia me rrethin 0.85
Spacing 1.0m
Visual Integration [HH]: 4.18 14.48 27.73
16
1:5000
Perimetri 1409
Kompaktësia me katrorin 0.47
Kompaktësia me rrethin 0.42
Spacing 1.5m
Visual Integration [HH]: 3.35 8.13 14.66
17
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Perimetri 278
Kompaktësia me katrorin 0.85
Kompaktësia me rrethin 0.76
Spacing 1.0m
Visual Integration [HH]: 13.58 845.90 31684.5
18
1:5000
Perimetri 900
Kompaktësia me katrorin 0.46
Kompaktësia me rrethin 0.40
Spacing 1.5m
Visual Integration [HH]: 11.99 24.77 46.08
19
1:5000
Perimetri 1280
Kompaktësia me katrorin 0.43
Kompaktësia me rrethin 0.38
Spacing 1.5m
Visual Integration [HH]: 4.11 9.57 16.87
20
1:10000