A new Relation Matrix as a Fruitful Meta-Design Tool

How to overcome typological limits

Ugo Maria Coraglia[1], Zhelun Zhu[2], Antonio Fioravanti[3], Davide Simeone[4], Stefano Cursi[5]
[1,4,5]www.aec-agency.com [2,3]Sapienza University of Rome
[1,4,5]{um.coraglia|d.simeone|s.cursi}@aec-agency.com [2,3]{zhelun.zhu|antonio.fioravanti}@uniroma1.it

The use of meta-design tools to support the early stages of the design process is widely proven in literature. Among these tools, the adjacency matrix and the bubble diagram provided the various professionals involved - not only in the AEC sector - with some useful information mainly regarding the connection types between spaces and the sizing of their dimensions. With the evolution of design and the change of architectural aims (e.g. sustainability, refurbishment), it is not fruitful, especially related to complex buildings (e.g. hospital, airport), to manage spaces and their connections through the traditional Adjacency Matrix and its dual (Bubble Diagram). These tools, used as they were originally designed, do not consider other characteristics but basic topological ones and are still linked to 2D geometry. For this reason, this research aims to increase the unexplored design potential of these tools considering huge advances in building object representation and links with knowledge. The first research steps led to a 3D analysis capable of providing knowledge on the connections and adjacencies between spaces and its environments located on different floors. Therefore, we decided to define further goals, breaking limits of the ``adjacency'' concept for a more extendable and general concept of ``relation'' between spaces and environments.

Keywords: *Relation Matrix, Meta-design, Architectural design theory, Tool*

STATE OF ART AND PROBLEMS

The design and construction of buildings - complex by their nature given the presence of multiple disciplinary domains - has always required a high expenditure of money, energy, resources, activities, and land usege. In the last decade (Monsù Scolaro, 2017) the approach of the experts has tried to favour a philosophy that foresees, if possible, the preservation and reuse of existing buildings and the redevelopment of those in a state of neglect.

An important aspect related to this type of approach that convinced professionals is that relating to sustainability. In fact, by not carrying out demolitions and relative displacements of waste materials, the use of new resources is avoided, unless radical transformations are necessary. Some British research institutes have found that the amount of CO2 produced per m^2 to build a new building is 4,5 times greater than the amount emitted for the renovation of an existing building. In fact, in regard to the production cycle and the transport phases inherent in a new construction, the data collected refer to 475 kg of CO2/m2 produced compared to only 104 kg of CO2/m2 emitted during a renovation. All this has been estimated in countries such as Great Britain by the stable demographic, social and economic structure, with a reduced seismic risk (VV.AA., 2008).

The challenge of improving and renovating existing buildings (e.g. hospitals, barracks, residences, etc.) has also fascinated internationally renowned architects, with remarkable results, such as Lina Bo Bardi in São Paulo for the transformation of a metal barrel factory (Vainer, 2013), MVRDV in Amsterdam for the conversion of silos [1], and Coop Himmelb(l)au in the redevelopment of three gasometers carried out in Vienna [2]. In the latter case, a building object of a purely industrial nature and of monumental dimensions has been transformed into a construction for residential purposes.

The building renovation design is often faced with the challenge of bringing the relationship between man and the building object back to a more human dimension and taking into consideration an architectural promenade, gradually closer, to appreciate the elements of beauty and richness of space at various distances and sizes (Baker, 1989).

However, the processes that characterize the renovation or reuse of buildings frequently have more similar approaches to the interventions of "fixing" and "repairing", mainly consisting of the following four operating methods (Figure 1):

- Change - change of intended use;
- Upgrade - improvement or expansion, A $\rightarrow$ A+;
- Downgrade - reduction or demolition, A $\rightarrow$ A-;
- Mix - combination of the previous three, A $\rightarrow$ A+ and / or A- and / or B.

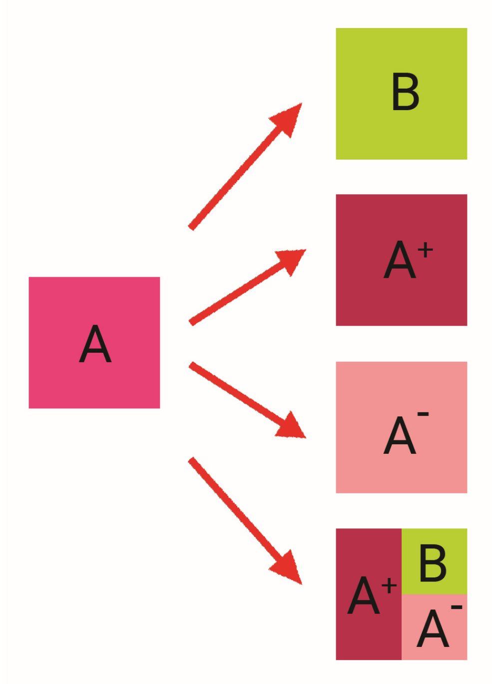


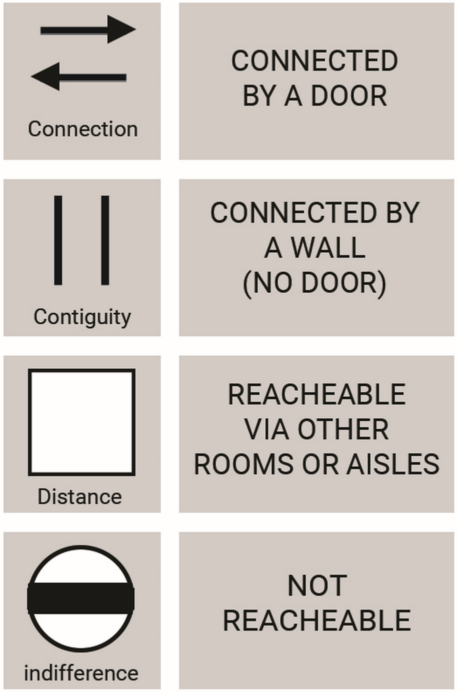
Figure 1
Existing building restructuring or re-use process characterizing solutions

The meaning of Upgrade and Downgrade, in this case, does not refer to the mere dimensional aspects but rather extends to the technological-performance aspects characterizing the building object under consideration and the functions performed within it.

In the integrated approach to the design and creative process of making architecture, a not negligible part - especially at the beginning of the current "Evo Informatico" - is due to the methodologies and technologies of ICT (Information and Communication Technologies), which allow to expand the design possibilities, providing tools as well as analysis, verification and optimization also for the production of new creative design solutions (e.g. architectural, distributive).

The world of CAAD (Computer Aided Architectural Design) is therefore not relegated to a marginal role in design but becomes the "characterization"

Figure 2
Adjacency matrix – Classic symbols



of a new scenario of possibilities, open to design in the broadest sense: Design theory. Fifty years have passed since the minting of this acronym which has dramatically expanded its branches and possibilities. It is known in fact how the development of ICT is so rapid that a single year of it equals ten years of the evolution of other sectors.

Some building construction "hybridizations" with ICT and other disciplines, carried out years ago, encountered objective computational or methodological difficulties, or insufficient understanding of design theory and were therefore abandoned. Now, however, they can be resumed and integrated into a design process that is more appropriate to current times. The reflection on these research focuses on the theoretical study of the design process and how the latter can become "autonomous" (Gerber, 2017).

The "automated" design solutions that were produced in the early years of the CAAD were so embryonic that they could not be considered an effective support for the designer's work. They were simplistic solutions that could be easily obtained with traditional methods.

One of the first results of these hybridizations occurred by associating the related geometry, Topology, with the bodies that represented the concept of "Room", generating and spreading the terms "Environmental Unit", "Space Unit", etc (White, 1986).

The basic idea was to associate the "vertices", representing the housing units, with the "edges", representing the connections between them, and consequently to verify objectively, automatically and in real time the compliance with predefined design constraints that they were limited to "connection", "contiguity", "distance" and "indifference" (Figure 2), such as to generate a matrix relating to the aforementioned adjacencies. This matrix was symmetrical with respect to the main diagonal, since the relationship, for example the "communication" one, could not specify whether this was bidirectional or unidirectional (Cocomello, 1980).

The relationships between the entities were formalized through algorithms which, processed computer-based, could immediately verify the correspondence to the two simple design constraints mentioned above. The approach proved to be sufficiently valid to verify these relationships in the presence of a project of extreme complexity where not all connections were visually perceptible while in simple projects, with few Environmental units, it was not very useful as these relationships were immediately perceptible (Coraglia, 2018a).

METHODOLOGY

The aim of this research is to introduce innovations in the adjacency matrix that will allow it and its automated processing to increase its validity to make to turn it into a better design tool. On the one hand they will concern new Environmental units and on the other new types of connections, also in the 3 dimensions, and related hierarchies.

The early stages led to propose as innovation an adjacency type relationship that is not only that in the plane, but also in the space and along the edges of the Environmental Units. This aspect is particularly useful because in the presence of disturbing sound sources one is able to understand immediately which Environmental Units are involved. And by switching to the BIM model, it can be checked whether the shared walls and/or floors are adequate as a soundproofing power for the disturbance suffered.

Since the graph is spatial, and there are no flatness constraints, you can hierarchize the Environmental units and explode the subsets of them without worrying about any intersections or apparent link inconsistencies.

On entities with a higher intelligence/abstraction layer, it will be possible to activate further generative rules, to produce new solutions based on rules, and to skim the design solutions, introducing other constraints. For example, spatial contiguities for the opening of temporary compartments during the execution of works can be used in construction site designs, as well as defining the optimized electrical diagrams for the length of the cables and optical fibres by resorting to the logical overlap affine geometry - Cartesian geometry. Always at a "layer" of intelligence, the logical links between the various Environmental units can be controlled.

Many of these checks and layouts can take place in the preliminary design phase, operating only on its typology, even before operating on an accurate design model. Hence the qualitative leap made on this new adjacency matrix results useful for the creative phase of the design.

The Adjacency Matrix relations in the case of a building recovery and/or renovation design are all known from the beginning. From this point on, the designer begins his creative work and focused on the details to be confirmed, modified or canceled. In the design of new buildings, the relations are only partially known because they are defined by the building program, by the parametric performance specifications and by the first design hypotheses. The other relations are, however, all to be invented, the result of the designer's skills and the relations that are refined during the course of the design itself. For this reason, as regards the aspect strictly related to adjacency, it was decided to "enhance" the types of relations between the Environmental units. The "enhancement", indeed, is to be understood both from the numerical point of view (increasing the entities, e.g. the external unit, etc.), and from the qualitative point of view (the adjacency relations in a vertical as well as horizontal way).

The symbol used to date - the two vertical bars || - and valid for any type of contiguity, it is no longer sufficient and is integrated with a new symbology that allows the professional to immediately receive much more information. In this regard, the symbology proposed in this research, based on the problems that may occur during the renovation and reuse works, takes into consideration not only the planimetric contiguity [||] but also the diagonal [//] and vertical [=] (see Figure 3). By diagonal contiguity we mean a "contiguity of edge" both planimetric and between different floors. The contiguity refers to the "Mix" type in the "State of the art" paragraph, in particular those works that may have to be carried out in parallel with the usual work activities characterizing part of the building object in question.

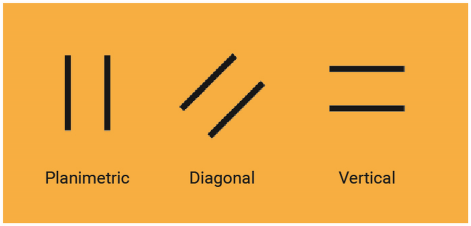


Figure 3
"Simplified"
contiguity

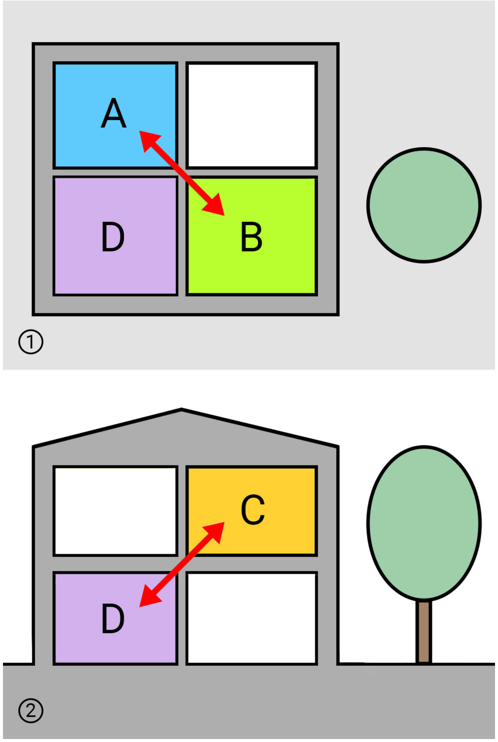


Figure 4
Diagonally adjacent rooms , horizontally (1) and vertically (2)

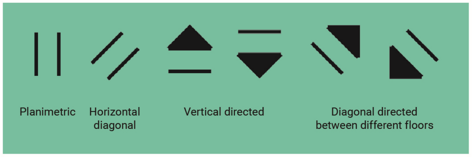


Figure 5
"Directional" contiguity

In fact, many times, especially within complex structures, such as hospitals, offices, etc., renovations activities can have a negative impact, for example due to noise and vibration, on the daily routines carried out within the areas of the building still in operation (Coraglia, 2018b). These negative impacts, which until now have only been considered for direct adjacency, communication or contiguity, through a shared wall, could also have repercussions on adjacent rooms diagonally, both horizontally and vertically (see Figure 4). Given that the renovations within complex structures may concern a multitude of rooms and floors, it is considered more correct to proceed further, detailing the first series of new adjacency symbols, henceforth defined as "simplified" contiguity, through a further specification of the two symbols just proposed. This additional new series of symbols, which has been defined as "directional", requires that the contiguity between different floors, upwards or downwards, both vertically and diagonally, be taken into consideration, as shown in Figure 5.

This specification, made necessary precisely by the analysis of negative impacts due to noise and vibrations, for example, allows the professional to immediately have a more detailed view of the problems that could be triggered through the implementation of certain renovation works. Further levels of specification have already been analysed but they have proved to have a negative impact on the understanding of the matrix that derives from it, which instead must remain fast and easy to read. For further degrees of specification, in fact, it is more correct to directly analyse the floor plans or the 3D model of the building in question.

In addition to what has been illustrated up to this point, to further expand the range of information obtainable through the consultation of the New Adjacency Matrix, it was decided to introduce some concepts that serve for evaluating the quality of a room, also introducing the qualitative relationship that this has with the other rooms, especially with the exterior.

The first concept we introduced is that of Luminosity, already expressed by E.T. White (1986) as the presence or absence of daylight according to the Low, Medium, and High classification. In our research, however, we decided to manage this information by classifying the window orientation characterizing the room itself, using a scheme that provides for the absence of a window [X = 0] or a specific value for each orientation [N = 1, W = 2, E = 3 and S = 4]. Switching to a classification with 4 parameters, instead of 3, allows you to further specify and differentiate the environments.

NB: in this paper, the orientation of the apartment and the windows has been simplified to only 4 cardinal points (N, E, S and W) but in Dynamo the algorithm has been programmed to obtain values from the BIM model with an accuracy of 1 degree.

Furthermore, as far as renovations are concerned, this data is useful both when you decided to open a new window and when it is assumed that two or more rooms join together.

The first situation gave the opportunity to introduce the Heat Dispersion coefficient, which takes into account the negative impact of the orientation of the window due to the lower radiation of the facades facing north in the northern hemisphere and south in the southern hemisphere [X = 0, N = –0.20, W = –0.10, E = –0.15, S = 0]. [3]

Given the numerous cases of the restructuring activity, the system proposed in this research takes into consideration the following 4 cases, useful for design purposes, which however have general validity:

1. 1 Room with (or without) 1 Window, this case serves as a basis for evaluating the quality of the room;
2. 1 Room with 2 Windows, in addition to providing an evaluation for a room characterized by 2 windows, allows us to evaluate the quality of a room whose renovation includes the addition of a window;
3. 2 Rooms with 1Window, in addition to providing the assessment of a large room, comparable to two rooms, characterized by a single window, allows us to evaluate the quality of a renovation that involves the union of 2 rooms, of which only one of these characterized by the presence of a window;
4. 2 Rooms with 2 Windows, in addition to providing the assessment of a large room, comparable to 2 rooms, characterized by the presence of 2 windows, allows us to evaluate the quality of a renovation that involves the union of 2 rooms, both characterized by the presence of a window.

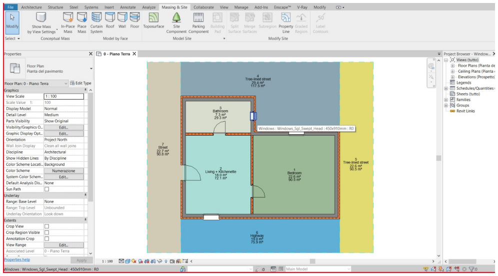


Figure 6
Revit model of a simplified apartment typology with 4 different external situation (N and E = tree-lined street, S = highway, W = street)

From case 2, foreseeing the presence of 2 windows, the parameters “Air flow” [flows from parallel directions (N-S, W-E) = 1, flows from perpendicular directions (N-E, S-E, S-W, N-W) = 0,5, absent = 0] and the “Light variation” [no window = -0.25, light from N = 0, light from E and W = 0,5, light from S = 1] have been introduced.

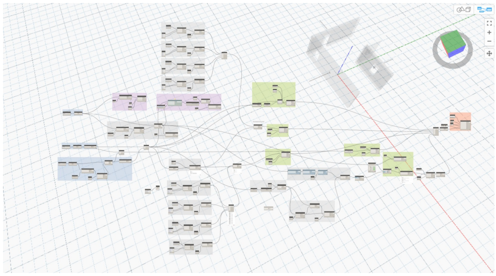


Figure 7
Dynamo workflow: from BIM model to Excel, useful data collection for the automatic evaluation of the room quality

Room ID	Window Orientation 1	Window Orientation 2	Window Orientation 3	Free Wall 1	Free Wall 2	Free Wall 3	POV rate 1	POV rate 2	POV rate 3	Connect. wall 1	Connect. wall 2	Connect. wall 3
Room 01	N	nf	nf	E	S	nf	4	4	-2	W	nf	nf
Room 02	S	nf	nf	W	nf	nf	-2	2	nf	N	E	nf
Room 03	E	nf	nf	W	N	nf	4	2	4	S	nf	nf

Table 1
Data collected by Dynamo (NB: nf = not found)

In the initial phase of a new project or immediately after carrying out an inspection for a refurbishment, using a BIM modeling software (such as the Autodesk Revit model shown in figure 6) it is possible to set up and enrich the model with information.

1Room 1Window				
Room	W01	Total value	POV W01	Total according to POV
Room 02	S	4	-2	2
Room 03	E	3	4	7
Room 01	N	1	4	5

Table 2
Room quality evaluation - Classification drawn up according to the Window Orientation (third column) and POV (fifth column)

This step is necessary to ensure that, using the Dynamo plug-in and through the setting of specific algorithms (see Figures 7 and Table 1), it is possible to automatically obtain the room quality evaluation, as

Table 3
Ranking of the best design solutions related to add a new window and sorted by Total value

1Room 2Windows																	
Room	WO1	WO2	OV1	OV2	Subtotal 1	Light Variation		Subtotal 2	Air flow	Heat loss		Area plus	Total value	POV WO1	POV WO2	Total according to POV
Room 02	S	W	2	4	6	1	0,5	7,5	0,5	0	-0,1	0	7,9	-2	2	8,3
Room 01	N	S	1	4	5	0	1	6	1	-0,25	0	0	6,75	4	-2	9,5
Room 03	E	W	3	2	5	0,5	0,5	6	1	-0,15	-0,1	0	6,75	4	2	13,5
Room 01	N	E	1	3	4	0	0,5	4,5	0,5	-0,25	-0,15	0	4,6	4	4	12,7
Room 03	E	N	3	1	4	0,5	0	4,5	0,5	-0,15	-0,25	0	4,6	4	4	12,7

illustrated in Table 2.

Furthermore, another aspect that has been taken into consideration to define the room quality even more in detail is the point of view (POV) that characterizes an existing window or the one that could be had in the case of a refurbishment that plans to equip the room for a further window. In Table 1, the data collected by Dynamo are organised in 4 blocks, Window orientation, Free wall (external walls without windows) , POV rate and Connected wall (related to wall connected to the rest of the apartment). Moreover, in Table 2, the last 2 columns on the right show the evaluation of the POV and the new total value of the room in accordance with the POV value.

For this reason, the following classification has been drawn up which makes it possible to simplify the evaluation of the relations of the external spaces with the room under consideration and make it compatible and collaborative with the other evaluations proposed so far:

- +5 Park, Heritage;
- +4 Square, Tree-lined street;
- +3 Courtyard;
- +2 Street;
- +1 Chiostrine, Alley;
- 0 Parking;
- -1 High density road;
- -2 Highway, Train station.

Thus, the ability to set the parameters within the BIM model and manage them through Dynamo has allowed us to expand the information that can automatically be provided to the designer. It is known that there are more accurate calculation systems that are suitable for calculating some of the information treated so far (e.g. sunshine of a facade, quality of air exchange) but each of them would be ineffective at this preliminary design stage because it would require a multitude of data not accessible at this phase.

Through the data collected by Dynamo, in addition to being able to automatically assign a value to each room, our algorithm is able to provide a ranking of the best possible interventions in reference to both the opening of a new window inside a room (see Table 3) and considering the union of two contiguous environments (see Table 4).

In both cases, the algorithm provides a ranking based on the Total values obtained by taking into consideration the parameters of Window Orientation, Light Variation, Air Flow, Heat Loss and Surface Increment (Area plus is a coefficient of 0.5 but can be 0 if there is no fusion between 2 environments).

Our simplification, of course, is open to be constantly updated with new parameters or to consider new levels of depth. The classification of the view from a window, in fact, could be implemented through the additional evaluation of the "Distance" parameter. This parameter would allow to evaluate differently, for example, the presence of a railway station, this in fact if placed in the distance - like skyline - could acquire an improvement coefficient instead of the negative one (-2) assigned to date.

CONCLUSIONS

This article, which is part of the still utopian concept of autonomous design, heir to automated de-

Table 4
Ranking of the best design solutions related to the merger of 2 rooms and sorted by Total value

2Rooms 2Windows																		
Room	Room	WO1	WO2	OV1	OV2	Subtotal 1	Light Variation		Avg. Light	Air flow	Heat loss		Area plus	Total value	POV WO1	POV WO2	Total according to POV
Room 02	Room 03	S	E	4	3	3,5	1	0,5	0,75	0,5	0	-0,15	0,5	5,1	-2	4	7,6
Room 01	Room 02	N	S	1	4	2,5	0	1	0,5	1	-0,25	0	0,5	4,25	4	-2	6,75

sign, aims to contribute to it through a piece, that of the automatic control of topological relationships redesigned in a more design perspective. In view of the new spatial relationships introduced and the new types of Environmental Units included in the Adjacency Matrix, the usual limitations imposed by this type of representation have been overcome, such as: the creation of a planar topology, the relationships exclusively between the Environmental and the adjacency relations only on the contact surfaces between the Environmental units. In this way, the generation of design solutions enriched by new relationships or constraints, which highlight additional information more useful for the design, allows to highlight the most appropriate subset of objectives required by the large number of automatically produced solutions.

This improvement of the assisted design tool is consequently placed within a wider field of man-machine co-design, trying to increase more and more the possibilities offered by the automated design, in view of the autonomous one, also facing a specific topic such as that of the management and control of adjacencies. In this way, the consequences and opportunities that came to light through the improvements of this representation can allow the designer to get rid of the repetitive and stressful controls inherent in the relationships between spaces and to focus, instead, on the most creative and exciting aspects of the design theme seen in its entirety.

Certainly, the process that will lead to automation is still very long and in some cases, for a sort of survival instinct or, perhaps, just for a kind of romanticism, some aspects related to emotions have been still left to the judgment and common sense of the designer. For this reason, the algorithm has been set up to provide rankings by ordering them by Total values and not by values recalibrated according to the POV. In other words, it was preferred to assign the responsibility of tipping the scales in cases of equal values after the POV evaluation.

In this case, the rooms were taken into consideration without considering the function attributed to them. Obviously, the evaluation of the function would involve an additional level of in-depth analysis. In fact, for example, more than one window is rarely designed inside a bathroom or kitchen and in this case we should set the algorithm to exclude these environments or take them into consideration for refurbishment activities that involve a change of window position.

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