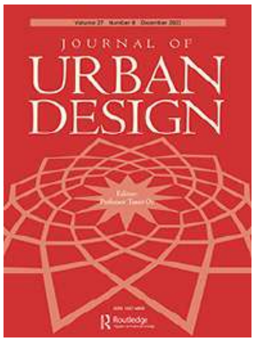

Journal of Urban Design

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjud20

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To cite this article: Mattia Bertin, Jacopo Galli & Francesco Rossi (2022): Retracing reconstruction. An assessment method for urban metamorphoses following extreme events, Journal of Urban Design, DOI: 10.1080/13574809.2022.2150157

To link to this article: https://doi.org/10.1080/13574809.2022.2150157

JOURNAL OF URBAN DESIGN
https://doi.org/10.1080/13574809.2022.2150157

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Retracing reconstruction. An assessment method for urban metamorphoses following extreme events

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ABSTRACT
Numerous research projects have faced the problem of the interpretation of post-disaster reconstructions. Several contributions have approached the problem in terms of identifying urban-setting reconstruction models, some attempting a systemization on a historiographic basis. To date, however, there has been no comprehensive work aimed at developing a quantitative method for evaluating and comparing reconstruction experiences. This article proposes a reproducible method for the systematic classification of post-disaster reconstructions, based on critical redrawing and data analysis. In the paper, the method is applied to 30 cases of reconstruction after the Second World War.

ARTICLE HISTORY
Received 21 Feb 2022
Accepted 17 Nov 2022

KEYWORDS
Evaluating reconstruction; disaster; reconstruction in Europe; geostatistics

Introduction and AIM

This paper proposes a quantitative classification method to describe the process of urban metamorphosis due to extreme events and the following reconstruction processes. The main features of the method are the tools applied, i.e., critical redrawing and standardized analysis. The novelty of the approach is then twofold. First, a quantitative method of classification is proposed, based on case comparisons using a set of standardized indicators instead of traditional categorizations based on the in-depth study of single cases. Second, the method aims to be repeatable and reproducible and, thus, less susceptible to subjective interpretation.

To define such a method, a cross-sectorial team was assembled, composed of an architect, an urban designer and a mathematician. The architect defined and carried out the critical redrawing of the case studies through the definition of a representation system capable of acting as the basis for the data analysis. The urban designer individuated and described the indicators needed to compare the different reconstruction models. The mathematician built and applied a standardized method of analysis.

The long-term goal of the research project is to apply this approach to any kind of disaster-induced urban metamorphosis, independently of the causes, locations and socio-economic conditions. For the purpose of this first test, the complexity was reduced by using a coherent set of case studies (Figure 1): European city centres reconstructed after

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/13574809.2022.2150157

N.	CITY	COU	DES	REC
01	Bochum	GER	1943	1965
02	Bremen	GER	1942	1955
03	Caen	FRA	1944	1957
04	Coventry	GBR	1943	1962
05	Den Haag [Vogelwijk]	NLD	1941	1965
06	Dresden [Altstadt]	GER	1945	1989
07	Dresden [Seevorstadt]	GER	1945	1989
08	Elblag	POL	1939	1983
09	Exeter	GBR	1942	1950
10	Frankfurt Am Main	GER	1944	2010
11	Hamburg	GER	1943	1960
12	Kassel	GER	1943	1970
13	Le Havre	FRA	1944	1964
14	London [Bankside]	GBR	1940	1968
15	London [Barbican]	GBR	1940	1982
16	Marseille [Vieux Port]	FRA	1943	1958
17	Milano	ITA	1944	1965
18	Münster	GER	1944	1964
19	Nürnberg	GER	1945	1971
20	Orleans	FRA	1940	1960
21	Pisa	ITA	1943	1960
22	Plymouth	GBR	1940	1962
23	Poznan	POL	1939	1965
24	Rimini	ITA	1943	1965
25	Saint Malo	FRA	1944	1961
26	Terni	ITA	1943	1954
27	Torino	ITA	1943	1959
28	Tours	FRA	1940	1962
29	Warsaw [Muranow]	POL	1939	1956
30	Wroclaw	POL	1939	1965

Figure 1. List and map of the geographical distribution of the selected case studies (with destruction and reconstruction dates): Bochum (1943–1965), Bremen (1942–1955), Caen (1944–1957), Coventry (1943–1962), Den Haag (1941–1965), Dresden (1945–1989), Eblag (1939–1983), Exeter (1942–1950), Frankfurt Am Main (1944–2010), Hamburg (1943–1960), Kassel (1943–1970), Le Havre (1944–1964), London (1940–1982), Marseille (1943–1958), Milano (194–-1965), Münster (1944–1964), Nürnberg (1945–1971), Orleans (1940–1960), Pisa (1943–1960), Plymouth (1940–1962), Poznań (1939–1965), Rimini (1943–1965), Saint Malo (1944–1961), Terni (1943–1954), Torino (1943–1959), Tours (1940–1962), Warsaw (1939–1956), Wroclaw (1939–1965).

the Second World War (WWII). The choice of this control group was made because of the long time that has passed since the events, which allows the reconstruction processes to be considered as being complete. Post-WWII reconstructions have also been intensively researched in monographic works, allowing the construction of a complete historical overview of the events. The examined case studies are distributed across Europe: France (6), Germany (9), Great Britain (5), Italy (5), the Netherlands (1), and Poland (4). The selection of the case studies attempts to balance a homogeneous geographical distribution, availability and accessibility of archival information available in the different national contexts. The different geographical distribution and features of the cities ensure a sufficiently large amount of data and maximize diversity among the case studies.

The research does not explore the characteristics of the effectiveness and efficiency of these reconstructions. It would have been misleading to unify a classification of typologies with an analysis of outcomes. The introduction of performance indicators could complicate the reading of the results and the repetition of the study. For this reason, the research leaves certain topics open to subsequent studies.

The structure of the paper corresponds to the step research process. The research steps are four in number: critical elements of historical categorization, critical redrawing, measurement of indicators and evaluation of their significance, development of the measurement synoptic chart. Critical elements of historical categorization trace the descriptions of the case studies considered in the literature and show a classification of the type of reconstruction, based on four categories of belonging. Critical redrawing redraws the outcomes of demolition and reconstruction with a common technique so that they can be superimposed, measured and compared. Regarding the measurement of indicators and evaluation of their significance, the standard indicators were selected and the value of each indicator was assessed in the comprehensive measurement of cases. The development of the measurement synoptic chart produces a synthetic framework of measurements, which enables an understanding of the relationships between the reconstruction models adopted in these cases. After the description of the research steps, the paper is concluded with a section dedicated to the outcomes and the future applications of the method.

Critical elements of historical categorization

Many studies have been devoted to post-disaster reconstruction with various focuses. This paper bridges the intersection of different research cultures on reconstructions. Some studies are dedicated to the definition of an historical perspective (Hippler 2014; Chapman 2005), while other studies have focused on the issue of cultural identity and heritage preservation (Bevan 2006; Bold, Larkham, and Pickard 2017; Allais 2018). Some studies focused on geopolitical and economic reverberations of reconstructions (Coward 2004; Iklé 2005), while others were dedicated to the use of ICT tools for investigative purposes (Weizman 2011, 2018). A large amount of research has investigated military tactics adapted to urban planning (Porteous and Smith 2001; Franke 2003).

In particular, the paper has deepened the research in the field of urban studies, where several contributions, mainly devoted to post-WWII Europe, aimed to develop an organized history of reconstruction processes (Mamoli and Trebbi 1988; Diefendorf 1990; Cogato-Lanza 2009; Johnson-Marshall 2010; Bakshi 2014) by exploring the different design approaches, in terms of urban and architectural strategies (Fabietti, Giannino, and Sepe 2013; Lindell 2013; Schwab et al. 2003; Vale and Campanella 2005). Some categorization has been attempted, based on the qualitative interpretation of urban metamorphoses following extreme events. Nevertheless a data-oriented method, based on measurable quantities, is still lacking.

For the purpose of this study, the research utilized the categorization proposed by Marcello Mamoli and Giorgio Trebbi in *L'Europa del Secondo Dopoguerra* (1988), within the seminal series *Storia dell'Urbanistica* published by Laterza. Despite being published in 1988, the book remains one of the most up-to-date, comparative studies in the field of urban design following WWII. The individuated categories, however, are purely historiographic and based on archival research and personal judgment; moreover, most of the research work focuses on the planning rather than on the concrete results of the urban metamorphoses. It is necessary to develop an alternative quantitative categorization mechanism which is capable of overcoming the critical elements of the qualitative categorization by comparing the evolutions in the urban patterns and identifying the key parameters that characterize the modification of the urban environment.

Mamoli and Trebbi's subdivision is composed of four categories, imagined for WWII Europe but which are potentially applicable (with minor adjustments) to other reconstruction processes triggered by extreme events:

(1) *as it was where it was*, in cities that carefully maintained heritage and memory by reconstructing the same urban pattern with the same building types (these include St. Malo, Münster, Warsaw, and Florence according to Mamoli and Trebbi's analyses);
(2) *continuity between tradition and innovation*, an innovative compromise that, while mandating the urban pattern, inserts new building types within a vision of modernization and functional improvement (Amiens, Caen, Lübeck, Terni, Milan, etc.);
(3) *rupture with the past*, a denunciation of destruction as an irreversible loss leading to a new urban pattern defined with new techniques but with similar building types (Hannover, Frankfurt, Livorno, Coventry, etc.);
(4) *programmatic innovation* in the few cases where reconstruction has been seen as the chance of a true re-foundation, with a completely new urban pattern and new building types (Le Havre, Rotterdam, etc.).

The categorization system proposed by Mamoli and Trebbi can be visualized as a synoptic chart, in order to position each case study in a relationship with the others, thus establishing the first qualitative categorization. Along the X axis, the synoptic chart describes the permanence or modification of the building type and, on the ordinate Y axis, the permanence or modification in the urban pattern. Each quadrant identifies one of the four categories, while the positioning of each case study can be decided through the careful analysis of the available materials, historic as well as interpretative. As yet, there

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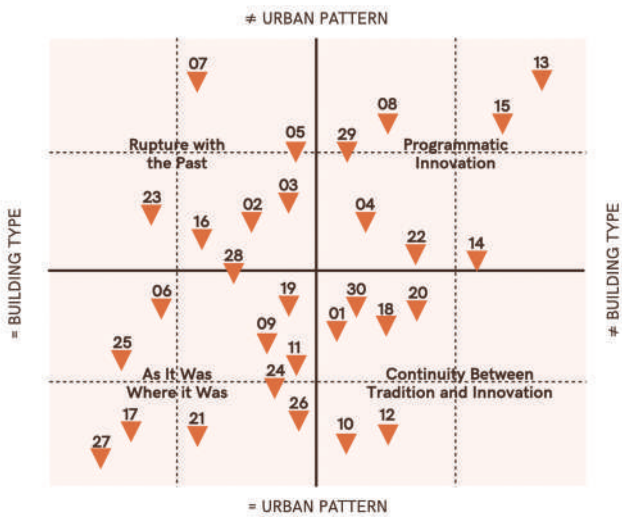

Figure 2. Literature synoptic chart showing the qualitative categorization method applied in a grid with the building type on the abscissa axis and the urban pattern on the ordinate axis. Each quadrant identifies one category, based on the subdivision proposed by Mamoli and Trebbi. All the case studies have been positioned in light of the available literature. Graphic restitution by authors, here in first publication.

are no numerical data to support this subdivision. The proposed chart is presented in Figure 2.

Critical redrawing

In order to construct an alternative quantitative categorization mechanism, the first step of the research was the definition of a common analytical approach for the different case studies, allowing the development of a comparison mechanism. The tool that was identified to carry out this research phase was ‘critical redrawing’, the rediscovering and updating of the methods for the description of urban transformations used, in particular. This concept was proposed in the books and urban designs by the world-renowned architectural historian and urban planner Leonardo Benevolo (Albrecht and Magrin 2015, 2016).

This research developed an analytical approach, adapting what Benevolo (1990) defined as *sceneggiatura delle trasformazioni fisiche* (screenplay of physical transformations), where architectural designs or urban environments are described and defined through all the specific characteristics of the object and its context, as would happen in a script for a film or theatrical production.

As an example, one of the most important scripts written and drawn by Benevolo is the clear illustration of the design processes developed for the San Pietro complex in Rome and presented in *Casabella* no. 572 in 1990 (Benevolo 1990, 2004). Benevolo’s screenplay identifies three key moments in the history of the urban complex through its critical redrawing:

(1) The condition of the square around 1660, before Gianlorenzo Bernini’s project.
(2) The completion of the colonnade with parallel arms and the definition of the ovoid square by Bernini, between 1662 and 1670.
(3) The current conditions, following the demolition of the Spina dei Borghi and the construction of Via della Conciliazione, after a design by Marcello Piacentini and Attilio Spaccarelli, completed between 1937 and 1950.

The three phases are not only described and documented but have also been drawn on the same scale and with the same type of representation, in order to eliminate the discrepancies arising from the different drawing styles. This method of analysis allows us to understand the reasoning behind each design choice, which cannot be explained through simple observation of the current state.

The final drawing proposed in the *Casabella* article is the transformation map (Figure 3), which is the cornerstone of the analysis: it superimposes the condition before Piacentini’s intervention on the current one and shows, with just three layers, the complex intertwining of urban continuities and interruptions that have characterized the urban history of the site. The drawing is presented in three simple colours: the red buildings are unchanged in the two periods, the yellow represents the demolitions and the blue the reconstructions, while the dashed yellow and blue shows the buildings that have been rebuilt on the site of previous buildings. The sum of these temporal layers provides a powerful tool for the understanding of urban metamorphosis. Time becomes a design factor, like space; the representation of the different time frames contributes to the

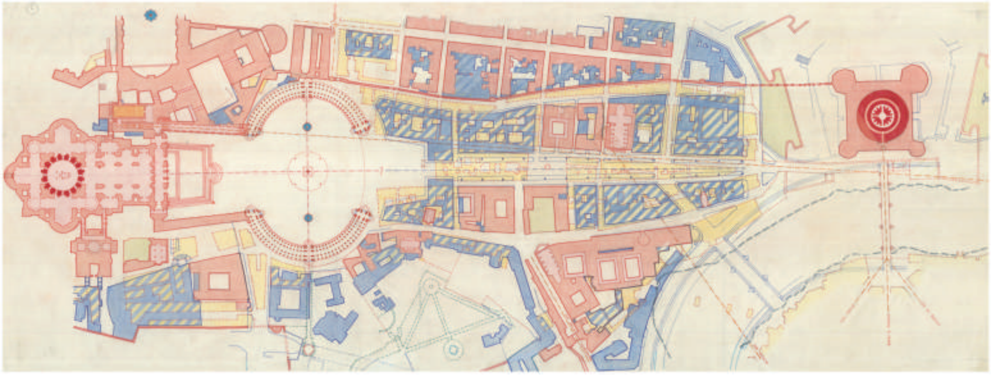

Figure 3. Transformation map of the Vatican with the overlap of Bernini's design and Piacentini's disembowelment. Source: Leonardo Benevolo, La percezione dell'invisibile: piazza san Pietro del Bernini, Casabella n. 572, 1990, pp. 54–60.

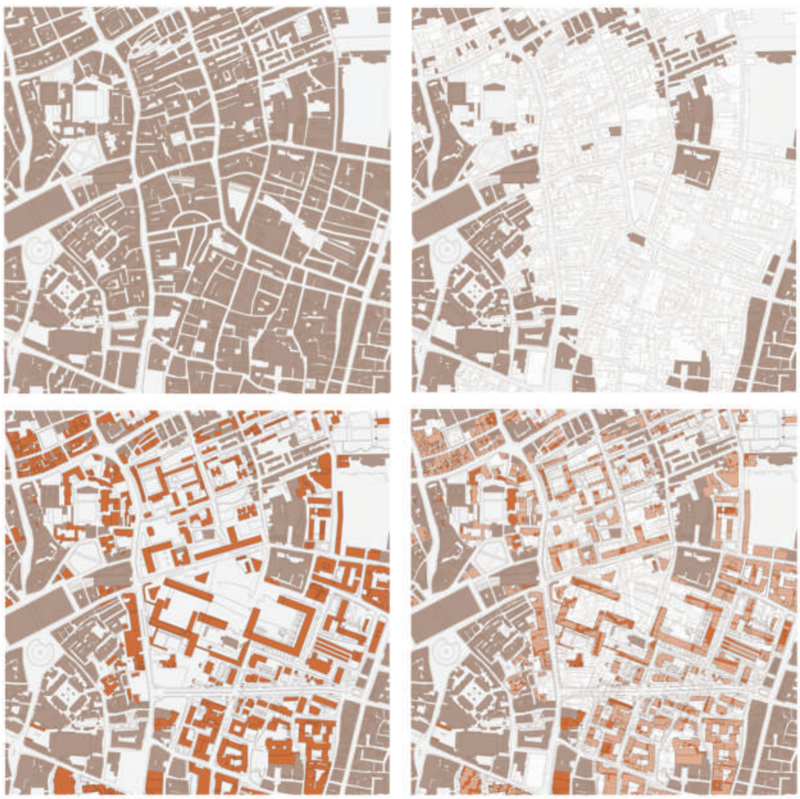

Figure 4. Maps D1–D4 for the Barbican Area in London, United Kingdom. D1 (top left) is the condition in 1940, D2 (top right) in 1944, D3 (bottom left) in 1982, and D4 (bottom right) is the transformation map 1944–1982. It is easy to see, in the D3 map, that the Barbican Centre was inaugurated in 1982 over the ruins of the previous medieval settlement.

understanding, not only of the evolutionary process but, above all, the visible structure in a central way. This is only the present concretization of complex phenomena that could, and still can, radically change due to future design choices.

The research team applied the transformation map tool identified by Benevolo (1990) to all 30 case studies identified above (as shown in Figure 4). The operation required a considerable amount of work in order to acquire the cartographic materials or historical photographs that document the state before the destruction, the level of destruction and the conditions at the end of the reconstruction process. The process of standardizing the different forms of representation, conducted through a careful redrawing, allows the elimination of the relevant discrepancies (scale, type of measurements, level of detail) and the achievement of a full overlap of the different time frame maps.

To make the data fully comparable, it was decided to redraw the same 1 km x 1 km frame for each case study. The standardized choice of the dimension of the frame was dictated by the average dimension of city centres destroyed in WWII which, in the vast majority of cases, fit a 1 km x 1 km frame completely. The definition of the frame for each case study was conducted with two main goals: to fully include the area with the highest level of destruction and to analyse urban patterns as homogeneously as possible. The homogeneity of the urban patterns allowed us to operate with elements of similar size and continuous density, thus avoiding the presence of objects of significantly different scales that might alter the computations.

While the time frames before and after the destruction roughly correspond to the beginning and the end of WWII, the time frames individuated for the end of the reconstruction processes, which allows the draft of the transformation maps, are a cornerstone of the analyses and vary significantly. In some cases, a site is characterized by destruction on a significant level in a restricted area and the reconstruction processes had already been completed in the 1950s (Marseille, Caen, Florence, etc.). Most of the planned large-scale reconstructions were completed in the 1960s (Le Havre, Rotterdam, etc.) while, in some examples, for economic or political reasons, the processes lasted until the 1970s (Kassel, etc.) or even until the 1980s (Dresden, London, etc.) up to the point of multiple reconstructions that extended well into the 2000s (Frankfurt). A formal date of completion for the reconstructions only exist in some cases of top-down planning, such as Le Havre (Etienne-Steiner 2018) where, in 1964, Auguste Perret's plan was declared complete, or Rotterdam (Blom, Vermaat, and de Vries 2017), where Cornelius Van Tra's basis plan remained in operation until 1968. In many cases, the completion of a symbolic building was used as the beginning or end of the reconstruction: in Milan (Pertot and Ramella 2016) it was the rapid reconstruction of the La Scala theatre, with the inaugural concert directed by Arturo Toscanini on 11 May 1946 and the completion of BBPR's Velasca Tower in 1957. In Marseille (Bedarida 2012), it was the 1954 inauguration of the new Vieux Port district, which was deliberately razed during the Nazi occupation and rebuilt on Fernand Pouillon's design. In London (Marmaras 2014; Stevens and Sumartojo 2015), the Cripplegate area saw a radical upheaval in urban forms, which culminated in the inauguration of the Barbican Centre in 1982. Each case study has been analysed using the relevant state-of-the-art research on the subject in order to individuate the evolution of the urban pattern (which is continuous and can never be considered fully completed), the moment at which the post-disaster reconstruction can be considered finished and in which to trace the transformation map. The choice of time frame is pivotal in the process, given that different time frames generate different transformation maps and, therefore, different results from the analyses.

Once all the key features for the critical redrawing had been identified, a set of drawings was produced for each case study, all drafted with the same graphic approach, which allowed clear understanding of the sequence of interventions and the process of morphological metamorphosis that led to the specific shaping of the urban environment at the end of the reconstruction. It is an operation, never carried out before in a comparative way, which makes it possible to re-evaluate the numerous monographic studies on post-war reconstruction processes (Cohen 2011; Düwel and Gutschow 2013; Moravánszky 2016) in light of a common evaluation system. Therefore, it allowed the definition of interpretative categories that are not limited to the observation of archival materials but are informed through the tools of redrawing and its interpretation. The redrawing allows the illustration of the three different urban structures before, during and after the extreme events and is concluded, as in Benevolo's example, with the drafting of a transformation map that overlaps the three moments and clearly shows the process of urban metamorphosis. The redrawing then produces the following:

(1) D1: Pre-Destruction Map;
(2) D2: Post-Destruction Map;
(3) D3: Reconstruction Map;
(4) D4: Transformation Map.

The systematic drafting of transformation maps makes it possible to compare the spatial consequences on the urban pattern of the various reconstruction strategies applied by giving a common analytical basis for the following design steps.

The transformation map of the city centre or the Altstadt area of Dresden (Figure 5), heavily destroyed between the 13th and 15th of February 1945, can be used as an example of the analysis of urban metamorphoses allowed by this tool. The few elements that are depicted in brown (zoom A) are those that did not witness a structural collapse and were simply restored; the fully dashed elements (zoom B) are buildings reconstructed precisely on the area previously occupied (in this case with the same architectural features, although this type of information cannot be traced by the map). Elements partially in orange and partially dashed (zoom C) are current buildings that occupy an area that, before the destruction, had a different urban configuration. Finally, the white elements (zoom D) represent empty areas that were occupied in the pre-war setting.

Figure 6 collects all the redrawing outcomes on a case-by-case basis. After this output, the measurement phase began.

Measurement of indicators and evaluation of their significance

The following step was the measure of indicators of urban metamorphosis. The key idea was to identify simple indicators that can be derived from the critical redrawing of the previous step, i.e., from plans during the three different time frames (D1–D3) and from the transformation map D4. By reviewing the fundamentals of urban planning theory and methods, the research identified some possible indicators of key characteristics of the built city. The choice of indicators is strongly indebted to two works in particular, setting

Figure 5. Transformation map of the case study of Dresden Altstadt with insets of four significant parts of the drawing, highlighting the buildings unchanged before and after the destruction (zoom A), those rebuilt on the site of the previous buildings (zoom B), those rebuilt with a new urban form (zoom C) and the areas previously occupied and left empty (zoom D).

a canon for the description and reading of urban spaces: *City Sense and City Design*, by Lynch (1995) and *Tecniche Urbanistiche*, by Gabellini (2001).

The computation began by computing a family of starting indicators, which are quantitative indicators describing synthetic features in the four maps (D1–D4) developed above (Table 1). The indicators needed to allow a repeatable measurement of built objects and their relationships in the urban environment, starting from two-dimensional maps. The elements had to be readable by a computation programme without any confusion, and without the intervention of an operator describing the objects 'map by map'. No data about the 3D structure of the city were present in the indicators due to the lack of reliable information of this kind before the reconstruction. All indicators were computed with standard mathematical tools, such as the ones implemented in MATLAB software. As an example, the number of elements before destruction SI2 was computed as the number of connected components in D1 by the standard function *bwconncomp*. The starting indicators (denoted as SI1 to SI13) are given in Table 1 below.

The values of the starting indicators for the case studies are provided in Table S1 in the online supplementary material. In Table 2, the starting indicators were processed for the example of Dresden Altstadt, as shown in Figure 5.

Since the research project was not focused on describing static conditions but urban metamorphosis, the starting indicators were used to build eight new transformation indicators that synthesize such change. Moreover, in the spirit of Mamoli and Trebbi's (1988) subdivision, the transformation indicators were divided into two categories: building type indicators (B1 to B3) and urban pattern indicators (U1 to U5). The categories and the indicators are reported in Table 3. The computation rules to pass from starting indicators to transformation indicators are also explained in the same table. It is crucial to observe that the transformation indicators B1-B2-B3-U2-U3 were computed with the

Figure 6. Transformation maps (D4) for each case study 01–30.

absolute variation of the corresponding indicators. This means that a variation in the parameter was computed without considering whether this variation was positive or negative. The reason behind this choice lies in the fact that axes in Mamoli and Trebbi's subdivisions describe variations in the building/urban elements, but do not differentiate between a reduction or an increase. Urban indicators U4 and U5 (being the complements to the 'preservation indicators' SI12 and SI13) were computed from the transformation map D4, which already quantified an urban metamorphosis.

After the computations given above, each index of each city was renormalized, with respect to the distribution of the index across all cities. The values of building and urban transformation indicators (before and after renormalization) are all provided in Table S2 in

Table 1. Starting indicators and drawings to which they relate.

Indicator Number	Name	Unit of Measurement	Computed from
SI1	Occupied area before destruction	km^2	D1
SI2	Number of elements before destruction	units	D1
SI3	Median size of elements before destruction	m^2	D1
SI4	Average distance between elements before destruction	m	D1
SI5	Squares area before destruction	m^2	D1
SI6	Destroyed area	km^2	D2
SI7	Occupied area after reconstruction	km^2	D3
SI8	Number of elements after reconstruction	units	D3
SI9	Median size of elements after reconstruction	m^2	D3
SI10	Average distance between elements after reconstruction	m	D3
SI11	Squares area after reconstruction	m^2	D3
SI12	Site maintenance	%	D4
SI13	Street-level maintenance	%	D4

Table 2. Example of compilation of starting indicators for the case of Dresden Altstadt.

Indicator Number	Name	Unit of Measurement	Value forDresden Altstadt
SI1	Occupied area before destruction	km^2	0.385779
SI2	Number of elements before destruction	units	103
SI3	Median size of elements before destruction	m^2	4954
SI4	Average distance between elements before destruction	m	11.87751105
SI5	Squares area before destruction	m^2	225,355
SI6	Destroyed area	km^2	0.373764
SI7	Occupied area after reconstruction	km^2	0.171927
SI8	Number of elements after reconstruction	units	61
SI9	Median size of elements after reconstruction	m^2	7277
SI10	Average distance between elements after reconstruction	m	14.43887629
SI11	Squares area after reconstruction	m^2	568,841
SI12	Site maintenance	%	81.01
SI13	Street-level maintenance	%	51.34

Table 3. Building and urban transformation indicators and computing formulae.

Building Transformation Indicator Number	Name	Computed as
B1	Absolute variation in number of elements after reconstruction over the number before destruction	|SI6/SI1-1|
B2	Absolute variation in median size of elements after reconstruction over the size before destruction	|SI9/SI3-1|
B3	Absolute variation in average distance of elements after reconstruction over distance before destruction	|SI10/SI4-1|
Urban Transformation Indicator Number	**Name**	**Computed as:**
U1	Destroyed area over area before destruction	SI8/SI2
U2	Absolute variation in occupied area after reconstruction over area before destruction	|SI7/SI1-1|
U3	Absolute variation in squares areas after reconstruction over areas before destruction	|SI11/SI5-1|
U4	Site variation	1-SI12
U5	Street-level variation	1-SI13

Table 4. Building and urban transformation indicators for the case of Dresden Altstadt.

Building Transformation Indicator Number	Name	DresdenAltstadt	Renormalized
B1	Absolute variation in number of elements after reconstruction over those before destruction	0.41	0.41
B2	Absolute variation in median size of elements after reconstruction over size before destruction	0.47	1.12
B3	Absolute variation in average distance of elements after reconstruction over distance before destruction	0.22	− 0.04
Urban Transformation Indicator Number	**Name**	**Dresden Altstadt**	**Renormalized**
U1	Destroyed area over the area before destruction	0.97	1.33
U2	Absolute variation in occupied area after reconstruction over area before destruction	0.55	2.07
U3	Absolute variation in squares areas after reconstruction over those before destruction	1.52	0.45
U4	Site variation	0.19	−0.09
U5	Street-level variation	0.49	0.97

the online supplementary material. For example, the transformation indicator shown in Table 4 was processed from Dresden Altstadt case.

At this point, two issues needed to be resolved: finding a method to understand whether all these indicators are necessary and giving a weight to the relevance of each indicator, when describing the reconstruction process.

Focusing on the aim of the project, a method which was completely driven by a statistical analysis of the data was chosen. Both issues were, indeed, met by choosing the *sparse feature selection* method (Witten and Tibshirani 2010): given a data set with some quantitative features, the method both selects the most relevant features and provides their relative weights.

Starting with a set of indicators, a sparse feature selection method distinguishes meaningful indicators from those that carry background noise. The method consists of searching for the minimum number of variables to robustly describe a phenomenon and its application allows the exclusion of insignificant variables and the identification of relevant ones. The method is sparse, in the sense that it aims to select a small number of features to prioritize synthetic indicators. Moreover, the selection of features, instead of creating new indicators based on mixing the original ones (as, for example, with principal component analysis), makes it possible to keep comprehensible selected features. The method was implemented with the software R. The results of the method, applied to the indicators above, are illustrated in Figure 7.

It is remarkable that the most significant indicator for measuring the metamorphosis was the number of elements. This means that such a quantity has a profound transformative capacity on an urban system in its different aspects, much more than other, apparently more significant, indicators (e.g., site maintenance or street size).

The significance computed above then assumed the role of a weight to compute the building and urban transformation scores for each case studied. The box below shows an example of computing a building transformation score.

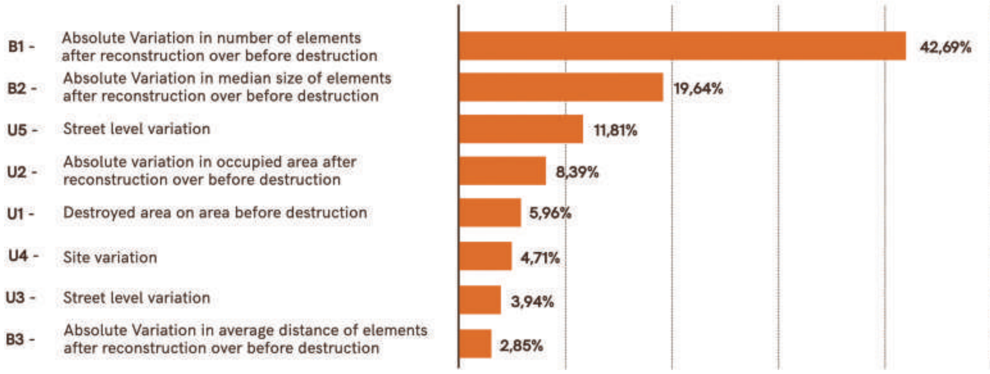

Figure 7. Results of sparse feature selection. Indicators are listed with decreasing weight (corresponding to significance), from B1 (42.69%) to B3 (2.85%).

$$\textbf{Building Transformation Score} = \text{RenormalisedB1} \times \text{WeightB1} + \text{RenormalisedB2} \times \text{WeightB2} + \text{RenormalisedB3} \times \text{WeightB3} = 0.41 \times 0.4269 + 1.12 \times 0.1964 + (-0.04) \times 0.0285 = \mathbf{0.3965}$$

It is important to note that a computed transformation score should always be considered to be a quantity relative to the average transformation of the studied cases. A large negative score corresponds to a small variation, a very small (positive or negative) score corresponds to a variation that is within the average of the case studies, and a large positive score corresponds to a large variation. In this respect, the scale of the scores is not really significant, as it only represents the variation in the weighted standard deviation (due to the renormalization).

Development of the measurement synoptic chart

This section shows the results of the method for identification of post-disaster reconstruction in urban settings based on critical redrawing (Section 3) and measurement of indicators of urban metamorphosis (Section 4). In particular, a new synoptic chart is compiled in this section, which is no longer based on historical in-depth interpretative studies but on quantitative measurements.

The method described in Section 4 provides a building transformation score and an urban transformation score for each of the 30 case studies. The scores are provided in Table S3 in the online supplementary material. The synoptic chart for the classification of urban metamorphosis has been reviewed using the scores as coordinates to define the position of the cases. Each case has a position determined by the building transformation score (x-axis) and the urban transformation score (y-axis). The distribution of cases is not intended as a precise objective position, since indexes can only be estimated and are based on comparisons with the available cases (and not with an objective scale). The chart needs to be understood in terms of 'domains of belonging'. Its significance is due to the fact that such a belonging is based on a quantitative measurement, rather than a historiographical appreciation.

The same analysis of a much larger quantity of cases (for example, derived from different causes of urban destruction) could modify the position described in the grid but the overall classification should be preserved.

The overall shape of the localization of the case studies in the chart can then be read as a cloud, which describes the general behaviour of reconstruction cases. Interpreting the shape of the cloud, a strong correlation appears between building innovation and urban innovation. In fact, the cloud is distributed in proximity to a straight line that cuts diagonally across the graph. Figure 8 shows the distribution found in the literature, the outcome of the measurements and the list of cases to facilitate a synoptic reading. As already mentioned above, the scale of the graph plays no role.

It is remarkable that the case of the Muranow area in Warsaw does not fit into the graph. Indeed, its building transformation score of 2.81 is an outlier with respect to other values in the measurement synoptic chart. The observation of the critical redrawing of the area (Figure 9) makes it possible to imagine that the complete change in the urban pattern (from a dense, low-rise fabric constructed in the mediaeval period to the high-rise, multistorey housing blocks of the Soviet era) generated a complete alteration in the overall values. This relevant exception, with a score dramatically different from other cases of complete destruction and reconstruction through programmatic innovation mechanisms, clearly shows that further studies are needed in order to properly reassess single historical cases.

Two superimposable graphs are now available, although they were produced using different methods. Each case has an initial position, retained from its description in the literature, and a final position, which is the result of the measurements of the indicators. Because of this difference in methods of generation, it is not possible to measure the

N.	CITY	COU	DES	REC
01	Bochum	GER	1943	1965
02	Bremen	GER	1942	1955
03	Caen	FRA	1944	1957
04	Coventry	GBR	1943	1962
05	Den Haag [Vogelwijk]	NLD	1941	1965
06	Dresden [Altstadt]	GER	1945	1989
07	Dresden [Seevorstadt]	GER	1945	1989
08	Elblag	POL	1939	1983
09	Exeter	GBR	1942	1950
10	Frankfurt Am Main	GER	1944	2010
11	Hamburg	GER	1943	1960
12	Kassel	GER	1943	1970
13	Le Havre	FRA	1944	1964
14	London [Bankside]	GBR	1940	1968
15	London [Barbican]	GBR	1940	1982
16	Marseille [Vieux Port]	FRA	1943	1958
17	Milano	ITA	1944	1965
18	Münster	GER	1944	1964
19	Nürnberg	GER	1945	1971
20	Orleans	FRA	1940	1960
21	Pisa	ITA	1943	1960
22	Plymouth	GBR	1940	1962
23	Poznan	POL	1939	1965
24	Rimini	ITA	1943	1965
25	Saint Malo	FRA	1944	1961
26	Terni	ITA	1943	1954
27	Torino	ITA	1943	1959
28	Tours	FRA	1940	1962
29	Warsaw [Muranow]	POL	1939	1956
30	Wroclaw	POL	1939	1965

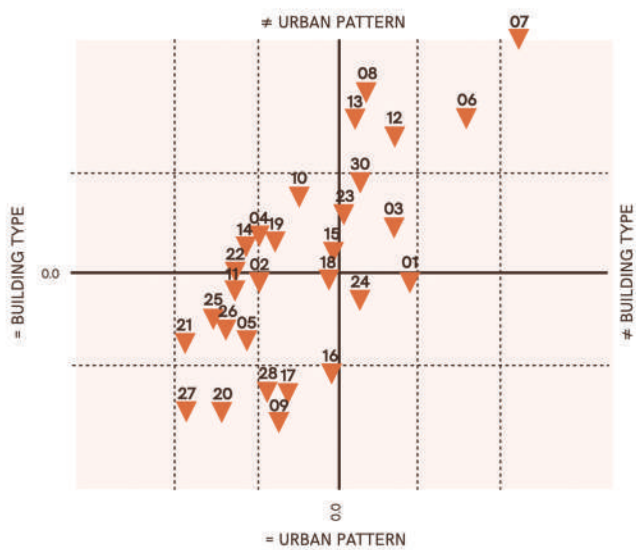

Figure 8. Measurement synoptic chart. Every case study is positioned on the grid, based on the results of the building and urban transformation scores. Graphic representation by authors, here in first publication.

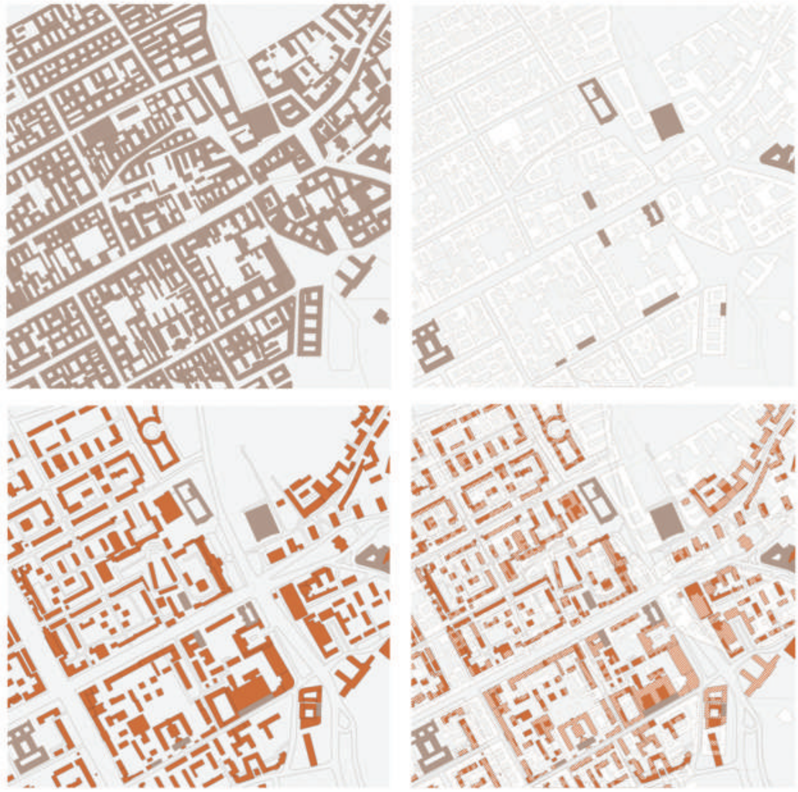

Figure 9. Maps D1–D4 for the Muranow area in Warsaw, Poland. D1 (top left) is the condition in 1939, D2 (top right) in 1945, D3 (bottom left) in 1956, and D4 (bottom right) is the transformation map of 1939–1956. The case shows a complete change in the urban pattern, which generates a high transformation score.

changes in position. However, it is possible to evaluate the number of displacements and the distribution of the displacement vectors as a whole. The comparison of the two point clouds (literature synoptic chart and measurement synoptic chart) allows an understanding of unforeseen evidence concerning reconstruction models. It is possible to determine an evident variation in the distribution and membership of the four quadrants.

Outcomes and future directions of research

The main outcome of this article is to propose a repeatable method for the evaluation of urban metamorphosis in post-disaster reconstruction, which can be re-iterated. The method can be replicated in all its parts: critical redrawing, measurement of indicators and classification. The final indicators, chosen and verified for their significance, provide a quantitative estimation of the urban metamorphosis, subdivided into building and urban transformations. The method provides a comparison table for different reconstruction cases and can be used as a frame of reference for the classification of additional cases (not treated in this article).

N.	CITY	COU	DES	REC
01	Bochum	GER	1943	1965
02	Bremen	GER	1942	1955
03	Caen	FRA	1944	1957
04	Coventry	GBR	1943	1962
05	Den Haag [Vogelwijk]	NLD	1941	1965
06	Dresden [Altstadt]	GER	1945	1989
07	Dresden [Seevorstadt]	GER	1945	1989
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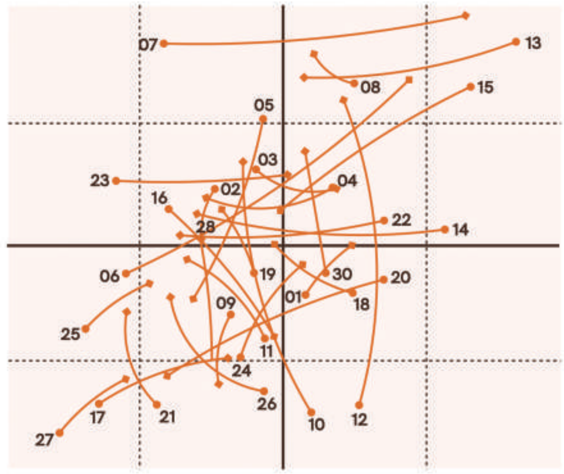

Figure 10. Variation in the position of each case study from the literature synoptic chart to the measurement synoptic chart. The point represents the initial position (literature), the square represents the final position (measurement).

The first novelty of the research is the comparison of two synoptic charts: the literature synoptic chart (Figure 2), based on a historiographical interpretation of the urban metamorphosis, and the measurement synoptic chart (Figure 7), based on critical redrawing and data analysis. By reading the alteration of the synoptic charts (as shown in Figure 10), it is clear that substantial relocation has occurred in many cases. This means that evaluation solely on the basis of the literature is not very effective when comparing different cases. Furthermore, a deviation this wide shows that developing general considerations on reconstruction models, without a standard measurement approach, can be misleading. It is likely that this discrepancy between the measurement of the cases (measurement synoptic chart) and the description of the cases in the literature (literature synoptic chart) is due to the different purposes of the two research models. The historical perspective was intended to recognize the possible strategies for urban reconstruction, an approach that is likely to increase the distance between the different options in order to offer a broader bundle of solutions. The article's measurement approach aims to understand the correlation between these options and to further refine this bundle by understanding relationships rather than diversities.

The second remarkable aspect is the shape of the cloud of points distributed on the measurement synoptic chart. Indeed, in the literature synoptic chart, the cloud tends to occupy the whole grid, without polarization. Instead, in the measurement synoptic chart, one can see a much less expanded distribution over the areas of the grid where architectural innovation and urban innovation do not proceed together. The cloud is polarized on a strong correlation between the degree of urban innovation and the degree of building innovation. One hypothesis to explain this polarization is that strong building innovation is not possible, or has never happened, without strong urban innovation, and vice versa.

The particular distribution assumed by the cloud leads us to ask whether this distribution is a characteristic of reconstructive choices or whether it depends on other factors. Is it possible that the analysis of a significant sample of reconstructions in North America or in the Middle East leads to the same shape? Is it possible that analysis of a sample of post-earthquake reconstructions in Europe would lead to the same shape? In essence, are there different cultures of urban and architectural design or is this diagonal shape innate to the ways of human reconstruction? The outcomes suggest a need for new studies to understand and design post-disaster reconstructions from an indicator-based approach of comparison and measurement. This is one of the most interesting new research directions that can be envisaged for the future of this method.

Conclusions

The research measures the placement of post-World War II European reconstructions in stable classes, considering the characters of urban and architectural innovation. The research used Leonardo Benevolo's transformation map (pre-destruction, post-destruction, reconstruction) redrawing method and standardized the approach. The indicators were chosen using a mathematical significance study. Indicators of the transformation of building types (in decreasing order of significance) are variations in the number of elements, variation in median size and variation in average distance. Indicators of transformation of the urban pattern (in decreasing order of significance) are street-level variation, variation in occupied area, destroyed area, site variation and variation in the squares area. When comparing the description in the literature and the measurement with indicators, the cloud of points distributed on the grid takes very different shapes. There is a strong correlation between grade of urban innovation and grade of building innovation in reconstruction, in most cases.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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