PAPER • OPEN ACCESS

Implementation of a Multi-scale Predictive System of the Degradation of the Urban Front in Brno, Czech Republic

To cite this article: A Torres *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **222** 012029

View the article online for updates and enhancements.

Implementation of a Multi-scale Predictive System of the Degradation of the Urban Front in Brno, Czech Republic

A Torres[1], L M Acosta[1], V Gibert[2] and C Serrat[3]

[1] Barcelona School of Building Construction, Universitat Politècnica de Catalunya-BarcelonaTECH, Dr Marañón, 44-50, 08028-Barcelona, Spain
[2] Dept. of Architectural Technology, LABEDI-EPSEB, Universitat Politècnica de Catalunya-BarcelonaTECH, Dr Marañón, 44-50, 08028-Barcelona, Spain
[3] Dept. of Mathematics, IEMAE-EPSEB, Universitat Politècnica de Catalunya-BarcelonaTECH, Dr Marañón, 44-50, 08028-Barcelona, Spain

carles.serrat@upc.edu

Abstract. The unavoidable deterioration of the built urban front in the cities has been increasingly generating a huge environmental impact. From this perspective, it is necessary to develop systematized methods that facilitate strategic maintenance of the facades and which study the variables that can potentially play a significant role in the damage occurrence. Therefore it is convenient to implement analytical methodologies to the decision making process on conservation and sustainability of the built urban front with a macro-scale approach. The BRAIN platform (Building Research Analysis and Information Network) is a Multi-scale Predictive System of the Degradation of the Urban Front. By means of periodic inspections, BRAIN allows analyses of damage progression and prediction of the future affectation, based on survival/reliability statistical models. The aim of this paper is to introduce a preliminary study on the implementation of the Urban Laboratory in the city of Brno, Czech Republic. Results of this primary approach have been displayed and discussed.

1. Introduction

The progressive degradation experienced by the urban front in the cities is a phenomenon in which the effects of various climatic factors are manifested. These in the socio-economic context may be related to the construction quality and the absence of a periodic preventive maintenance protocol. The deterioration of the built urban front results over time into the shortening of the useful life of the buildings and promoting the replacement of the built entities generating adverse environmental effects. In this sense, the current research presents an approach that seeks conservation of the built urban front through implementation of a methodology which, by means of the survey and statistical processing of multi-scale sample data, allows the assessment of the state of the facades and an estimation of their potential future deterioration. In the presented methodological framework, the data and variables to be considered were obtained through the implementation of a specific Urban Laboratory, in this case the data corresponds to the Urban Laboratory in the city of Brno in the Czech Republic, developed in 2017 and presented in Acosta and Torres (2018) [1].

2. Methodology

The BRAIN network (Building Research Analysis and Information Network) [2], representing the framework under which the methodology was developed, was designed so that it could be adapted to any Urban Laboratory in the world. The data obtained in each case study can be processed separately or jointly with the ones from other locations, in the unit called Collaborative. Similarities and differences related to the nodes (Urban Laboratories) can be analyzed and verified, taking into consideration particular territorial and environmental variables that influence the durability of a set of facades.

Methodology of a preliminary pilot study focuses on the analysis of the elements of the buildings exposed to the street environment taking into the account that the main facade, as a subsystem of the building, is the one that receives the highest impact of the phenomena that can reduce its durability. In this sense, the geometric space between the facades on both sides of a street, known as the urban canyon, constitutes the environment container for the data necessary for the development of an urban laboratory according to the protocol proposed in the Multi-scale Predictive System of the Degradation of the Urban Front [3], which focuses on the study of residential buildings.

2.1. The inspection protocol

Monitoring process allows to identify the moment when the facade service life affectation occurs and to predict its progress over time [4]. In order to reach this objective, the inspection of facades is carried out according to the protocol designed by Gibert (2016) [3], which is based on the creation of a database in which the information corresponding to the state of conservation of each facade is stored over time. To facilitate the collection of data, the protocol includes an inspection document, which is divided into two parts: a first part a) for collecting general data of the building and a second part b) for the evaluation of the existing damage to each of the facades exposed to the street environment, allowing subsequent management and statistical analysis of the data.

The inspection document was designed taking into account series of requirements with a population approach [5]. The document also includes a categorical division of the elements and areas that make up the facade, in order to accurately collect the magnitude and severity of the facade damage so that the data is hierarchically recorded for further processing.

Each injury or lesion is evaluated according to its extent by means of a visual approach: puntual (P) when less than 25% of the element is damaged, local (L) when damage affects between 25% and 50% of the element, and general (G) when damage exceeds 50% of the element. Injury is also evaluated in terms of severity by assigning a numerical value from 0 to 6, according to the severity of the injury observed, to each of the element.

2.2. The statistical analysis of data

To convert the data into useful information, a descriptive analysis of the inspected sample has been carried out, establishing the particularities detected that allow recognition of the buildings stock under analysis. The information collected on the extent and severity of injury allows calculating, numerically and graphically, the Weighted Severity Index (WSI) of the injury as a weighted mean which allows the researcher to obtain a general image of the overall condition of the facade injury. WSI can be calculated for each injury or for a part of facade.

If $\mathcal{E}$ represents the set of existing elements on a facade, WSI of the facade concerning a particular injury is given by the weighted mean of the injury severities, across the elements in $\mathcal{E}$, with weights 1, 2 and 3 for the extent variable, that is represented by the equation:

$$WSI = \frac{\sum_{i \in \mathcal{E}} (P_i + 2L_i + 3G_i)}{18 \cdot card(\mathcal{E})} \cdot 100, \qquad (1)$$

where P_i, L_i and G_i represent the severities with puntual, local and general extent, respectively, being 18 (= 3·6) the potential maximal effect of the injury, and $card(\mathcal{E})$ the cardinal of $\mathcal{E}$, i.e. the number of existing elements. The WSI represents the percentage of injury, in terms of severity and extent, of every facade and it is calculated for each of the aforementioned injuries. When calculating WSI for each part of the facade (body, deck railing, balconies and tribunes), the constant 18 in the denominator of the Equation 1 is replaced by 144 (=18·8) after taking into account the overall impact of eight injuries that are considered in the study. Figure 1 shows data for a particular facade.

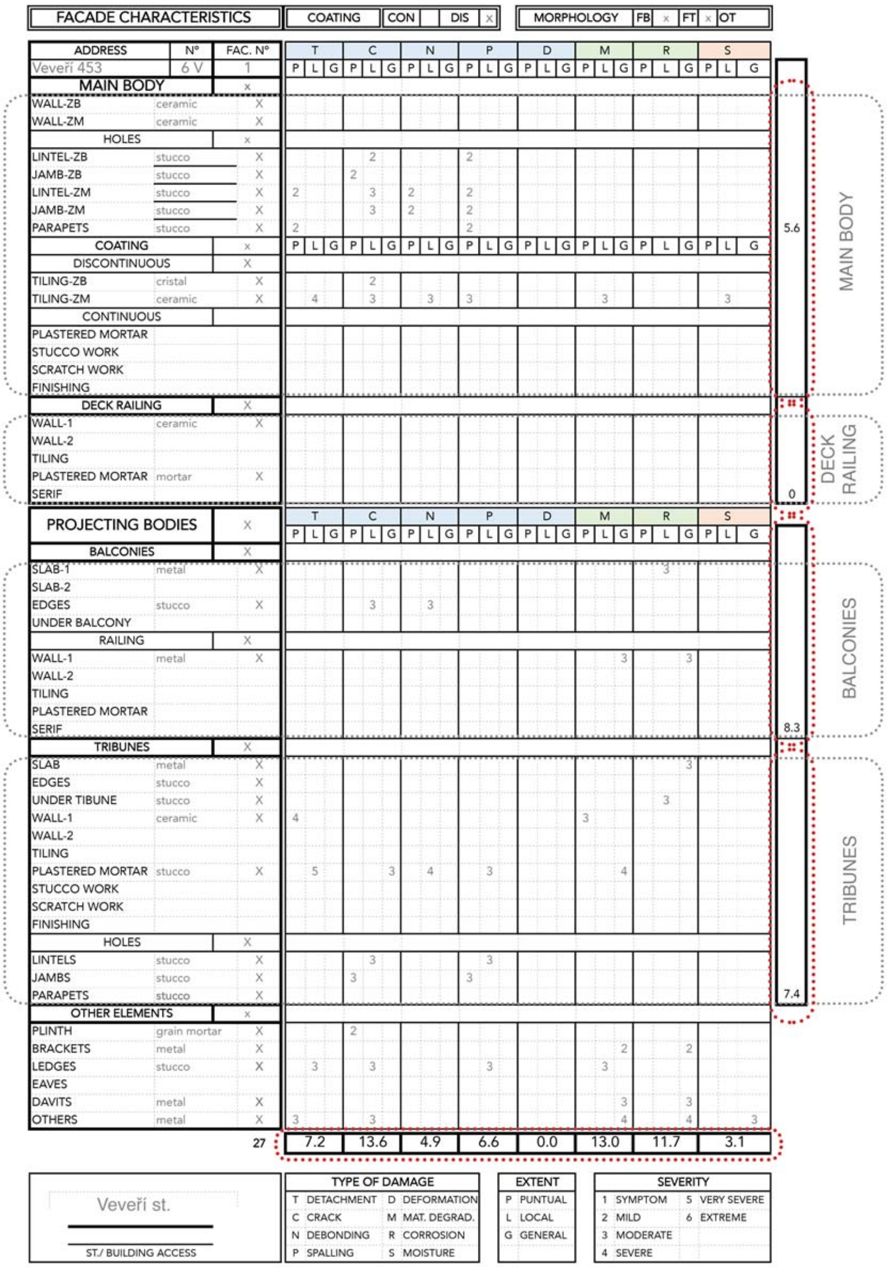

Figure 1. Example of part b) of the inspection document (the resulting WSI values are highlighted for the case of a particular facade).

3. Urban Laboratory in Brno, Czech Republic

Implementation of urban laboratories has been carried out in several countries, taking into account the collaborative nature of the BRAIN methodology; in this section the paper presents the particular case of the Urban Laboratory implemented in the City of Brno, Czech Republic.

The implementation was carried out in the period between October and November 2017. The Urban Laboratory pilot study was located within the boundaries of the Veveří District, which has a noticeably urban character with several heavy traffic streets that connect it to the historical centre and a cadastral surface area of 1.98 km^2.

3.1. *Studied sample*

The selected sample consists of a group of 100 facades of residential buildings. The inspected facades are located mainly in Veveří and Jiráskova streets, out of which the Veveří street is the one of greater width and heavier traffic. In this case, the selection criteria of the sample took into account the historical-cultural relevance of the buildings and the interest of the municipality. Figure 2 shows the sample selected for the analysis.

Figure 2. Map of the sample of interest in the Veveří District, Brno, Czech Republic (buildings with the inspected facades are marked in blue, n = 100).

Out of the analyzed sample, 90 facades were public owned buildings, 70 had flat facade morphology and 76 had a continuous lining, generally of lime or cement mortar. Figure 3 shows the number of facades suffering individual injuries. It can be clearly seen that cracks, spallings and detachments represent the most frequent injuries in the sample. This result was expected due to the type of materials used on the higher percentage of inspected facades.

3.2. *Weighted analysis of damage*

For the purposes of this study, the importance of observing the behavior of the detected injuries in macro-scale has been highlighted. Within this perspective, WSI values were calculated for each inspected facade and they were plotted on a territory plan. Details on these maps can be found in Acosta and Torres (2018) [1].

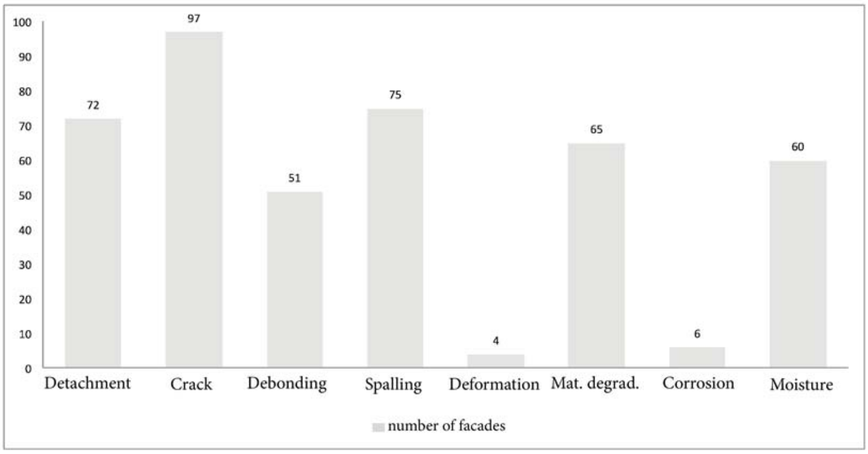

Figure 3. Number of facades suffering each one of the injuries.

It can be deduced from these analyses that the highest values of Weighted Severity Index (WSI) were located in Veveří Street, with the exception of cases of spalling damage whose WSI values were evenly distributed in both streets. Table 1 shows the descriptive statistics of the WSI values distribution and the corresponding Boxplots are shown in Figure 4. On the one hand, it is interesting to note that cracks' WSI values distribution is the one presenting the higher statistics and the most skewed-to-right Boxplot, according to its presence in the sample. On the other hand, Boxplots in Figure 4 allow detecting outlier facades which need a more urgent maintenance intervention.

WSI	N	N*	Mean	SE Mean	StDev	Q1	Median	Q3	Maximum
Injury									
Detachmet	100	0	4.08	0.55	5.55	0.00	2.50	5.60	30.00
Crack	100	0	9.93	0.73	7.33	4.80	7.85	14.93	43.30
Debonding	100	0	1.74	0.25	2.52	0.00	1.00	2.80	12.80
Spalling	100	0	5.16	0.71	7.13	0.15	2.80	7.05	43.90
Deformation	100	0	0.08	0.04	0.38	0.00	0.00	0.00	2.50
Material Degradation	100	0	6.47	1.02	10.24	0.00	2.55	6.78	41.70
Corrosion	100	0	0.32	0.15	1.54	0.00	0.00	0.00	11.70
Moisture	100	0	2.42	0.35	3.51	0.00	1.10	3.70	18.50
Part of the façade									
Body	100	0	3.19	0.38	3.76	0.83	1.90	4.10	24.10
Deck Railing	7	93	0.90	0.90	2.38	0.00	0.00	0.00	6.30
Balconies	20	80	4.05	1.26	5.65	0.83	1.75	5.63	22.60
Tribunes	7	93	1.60	1.08	2.86	0.00	0.00	3.50	7.40

Table 1. Descriptive statistics for WSI.

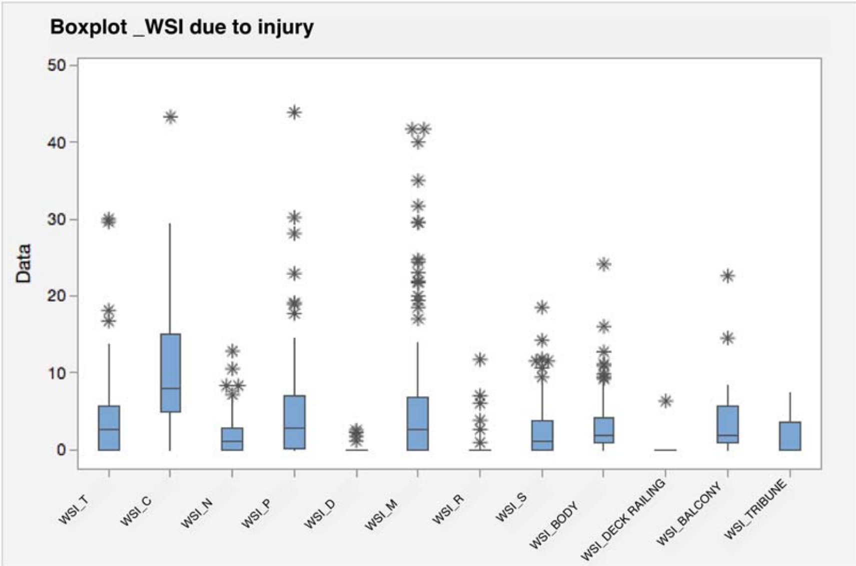

Figure 4. WSI Boxplot per injury and part of the facade.

3.3. *Temporal evolution of severity*

In the framework of the Multi-scale Predictive System of Degradation of the Urban Front [3], a relevant aim is to predict the progression of the facade condition over time, as well as to check the differences among different construction periods. At this preliminary level of the Urban Laboratory implementation in Brno, only one inspection per facade was done which does not allow an accurate prediction of the estimation. However, the existence of a relationship between the construction period and the facades' level of conservation or deterioration was explored. The analysis was performed with the subsample of facades for which the record of the construction date was available.

Figure 5 shows how the construction dates are distributed, where it is possible to see the potential existence of two groups, according to the construction century. This fact motivated splitting of the subsample in two categories for XIX and XX centuries, respectively.

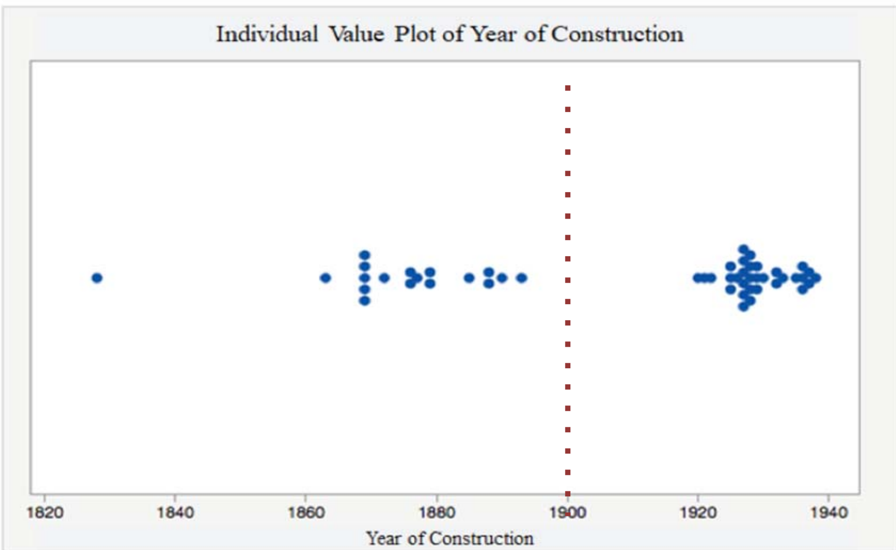

Figure 5. Distribution of the subsample according to the year of construction.

After defining these two subsamples, XIX and XX centuries, a comparison of independent samples was made through a t-Student test checking for differences among the respective WSI values. The comparison was made for each of the eight injuries and for the four parts of the facade: body, deck railing, balconies and tribunes. Graphical descriptive results have been plotted on categorical Boxplots in Figure 6 and the results of the statistical tests for the differences are shown in Table 2.

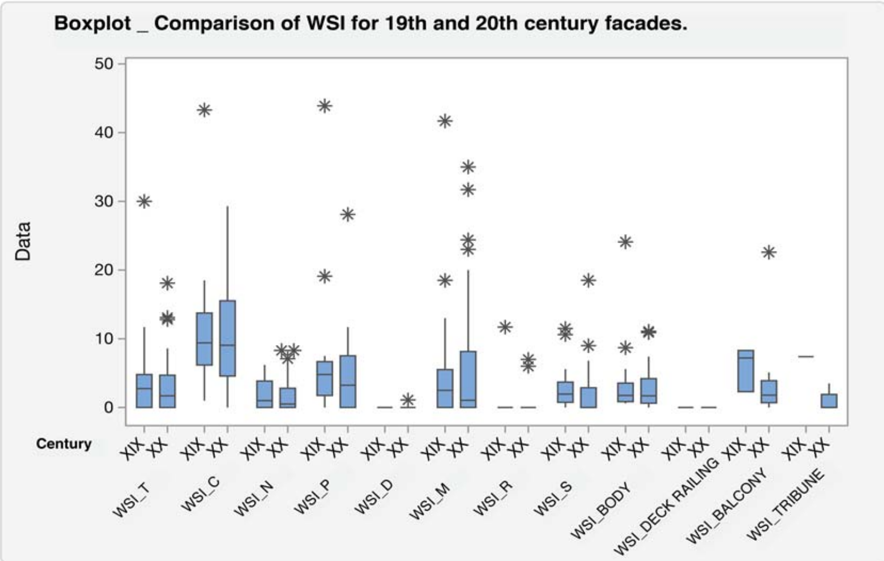

Figure 6. WSI Boxplot per injury and part of the facade, stratified per construction century.

WSI	Difference	95% CI for difference	t-value	DF	p-value
Injury					
Detachmet	1.16	(-2,64 ; 4,97)	0.63	24	0.534
Crack	1.24	(-3,94 ; 6,42)	0.49	28	0.627
Debonding	0.10	(-1,28 ; 1,48)	0.15	39	0.808
Spalling	2.21	(-3,20 ; 7,62)	0.84	23	0.407
Deformation	-	-	-	-	-
Material Degradation	-0.31	(-6,43 ; 5,81)	-0.10	34	0.919
Corrosion	0.24	(-1,22 ; 1,71)	0.34	23	0.734
Moisture	0.81	(-1,28 ; 2,91)	0.78	39	0.438
Part of the facade					
Body	0.91	(-2,00 ; 3,82)	0.65	22	0.525
Deck Railing	-	-	-	-	-
Balconies	1.77	(-5,14 ; 8,67)	0.59	8	0.572
Tribunes	-	-	-	-	-

Table 2. Test of WSI means comparison according to the construction period.

Both Figure 6 and Table 2 state that differences in WSI values do not exist for any injury or part of the facade. Boxes are overlapping and all the *p*-values for the tests are higher than a 0.05 significance level. So, there are no significant differences in the facade condition according to the construction period.

4. Conclusion

Application of the inspection methodology with a multi-scale approach has allowed an analysis of the state of deterioration of the studied sample. It has also made possible the identification of particular cases in which the presence of outlier data highlights the need for specific interventions. It has been also proved that, for the studied sample in this preliminary research, there a no significant differences between the facade construction periods, neither per the injury nor per the part of the facade considered in the paper.

Acknowledgements

To carry out the objectives of this paper within the framework of the Brno Urban Laboratory, we collaborated with multiple entities. The authors wish to express their gratitude to Barcelona School of Building Construction (EPSEB), the Institute of Statistics and Mathematics Applied to the Building Construction (IEMAE) for the analysis of the data, the Building Laboratory (LABEDI) on account of the methodology proposed in this study, the Brno University of Technology (BUT), in combination with the Advanced Materials, Structures and Technologies Laboratory (AdMaS), and the City Council of Brno for the support during gathering the information from the urban laboratory. This research has been partially supported by grants Nos. MTM2015-64465-C2-1-R (MINECO / FEDER) of the Ministerio de Economía y Competitividad (Spain) and 2017 SGR 622 from the Departament d'Economia i Coneixement de la Generalitat de Catalunya, and the SmartTransLog Erasmus+ Consorcium (2016-1-ES01-KA108-023465).

References

[1] Acosta L and Torres A 2018 *Implementación del Laboratorio Urbano de Brno (República Checa) en el Entorno BRAIN. Fase I* (in Spanish), Master Thesis, Universitat Politècnica de Catalunya-BarcelonaTECH.

[2] Serrat C, Gibert V, Casas J R and Rapinski J 2017 BRAIN: Building Research Analysis and Information Network *Proceedings of the XIV International Conference on Durability of Building Materials and Components* (Belgium, Ghent: Ghent University).

[3] Gibert V 2016 *Sistema predictivo multiescala de la degradación del frente urbano edificado* (in Spanish), PhD Thesis, Universitat Politècnica de Catalunya-BarcelonaTECH

[4] Serrat C, Gibert V, Casas J R and Rapinski J 2017 On the selection of significant variables in a model for the deteriorating process of facades *IOP Conference Series: Materials Science and Engineering* **251** 012071.

[5] Gibert V, Serrat C and Casas J R 2014 Determination of criteria for the exploration and for obtaining indicators in evolutional analysis of degradation in urban facades *Proceedings of 13th International Conference on Durability of Building Materials and Components* Sao Paulo pp 656–63.