Factors Determining Technical Wear on the Example of the Analysis of the Technical Condition of Balconies in Multi-Family Housing

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Abstract. The problem related to the technical wear of the building affecting the state of the structure is crucial from the end user perspective. It influences the maintenance phase in the life-cycle of the object. Researchers agree that knowledge about factors influencing the technical state of the construction is important in terms of cost estimation of works needed for keeping the object in appropriate conditions. The article presents the idea of determining technical wear of the construction, based on the detail analysis of the technical condition of balconies. Authors focus their attention to present possible aspects of technical wear of the building, especially considering external conditions influence on the construction. For this purpose, investigation was performed on the set of 74 balconies located in the block of flats in city of Poznań, Poland, where modernization is planned to be done within the next 12 months. Authors prepared detailed analysis taking into account current technical state of among others: handrails, balustrades, walls, upper plate, bottom plate, floor surface, flanks, plasters etc. From the analysis report was prepared showing what are the most intensive technical factors influencing state of the building and how they affect visual and constructional aspects of balconies. Based on those information, authors came to the conclusions that due to different errors committed on the phase of executing construction works, as well as adverse and aggressive weather conditions, state of the structure can show faster tendencies to destruction, which from the end-user point of view can cause problems and results in the need of costly repairs.

1. Introduction
Buildings are one of the largest energy consumers in society [1]. Especially in European climate most energy in the building life cycle is dedicated to heating [2]. More than 70% of the existing buildings in EU have been built between the ‘50s and the ‘70s, in the total absence of any specific regulation regarding buildings performances, energy consumptions and savings [3]. The majority of those buildings have been modernized in terms of heat insulation. Nowadays we can observe that also building constructed in 80s and 90s are in the need of some improvements, corrections and modernization which is a part of current EU law objectives and initiatives [4].

It can be observed in Poland, that step by step more paid costs by housing cooperatives happened from various reasons:
• Ecology,
• Maintenance cost,
• Heating costs,
• Visual aspects.
In the literature there are limited studies and consensus on the concepts of façade modernisation for renovation or refurbishment [5] and recent efforts to date do not address sustainability issues comprehensively [6]. This is the reason that topics related to the condition of the façades needs to be further investigated to enable for future generation the possibility to further use buildings constructed in the past. This also presents authors motivations to perform analysis related to the façade conditions with the main focus on the balconies, considering dependence on the changing environment conditions, which is in general one of the characteristic feature of the building [7].

2. Technical condition of balconies
The starting point for the correct design of a balcony, terrace or loggia is:

- precise definition of the function that you want to petition in the future,
- analysis of the structural diagram,
- identification of loads and destructive factors,

and then on the basis of the adaptation of technically correct materials and structural solutions (they will be systemic anti-moisture insulation, thermal insulation, drainage devices, and finally systemic material solutions for structural and surface protection) [8]. The second, equally important stage, is construction in accordance with the art of construction. These two processes should interact with each other; however, current tendencies prefer minimalism, beginning with the lack of a comprehensive analysis of phenomena occurring in the designed elements, and ending with omitting drawing details and construction details in the design [9]. Each of those steps requires proper communication between people involved in the process, as communication is crucial for correct execution of construction projects [10].

There are existing many common errors, which can be divided into the following categories [9]:

Errors made at the design stage:
- the use of materials that are inadequate to external conditions (loads, operating conditions),
- errors in the dimensioning and reinforcement of the board structure (resulting in e.g. excessive deflections or scratches of the structure),
- incorrect solution of the method of damp insulation and drainage (selection of inappropriate materials, lack or incorrect design of flashings),
- incorrect arrangement or design of dilatation,
- incorrect use of materials, lack of systematic solutions, failure to take into account the need to comply with technological regimes, non-adaptation of surface layers to conditions or operational needs.

Errors made at the execution stage:
- deviations from the project, execution incompatible with regulations and the art of construction,
- technological defects,
- the use of materials of low quality, inadequate identification or preparation of the substrate, incorrect dosing of ingredients, insufficient mixing, application errors (regarding time, temperature, humidity, technology), non-compliance with performance regimes and technological breaks (sometimes indolence and arbitrariness),
- saving on materials - resignation from some layers of the system, application of cheaper solutions from outside the system.

Material errors include:
- lack of proper proportions between individual components in the manufacturer's packaging or when dividing larger packages (applies to multi-component products),
- the use of expired material (having caking, characterized by the lack of homogeneity, binding or extended setting time, partial crystallization of components), qualitative errors committed at the production stage (i.e.),
- freezing of products during transport or storage (applies to a period of low temperatures).
- errors made at the stage of operation are: overloading the balcony structure, excessive load,
- other damage (e.g., punctures, installation of additional elements, etc.), failure to carry out necessary repairs and lack of maintenance.

Presented list shows that process of designing and execution of works to proper use of the balconies is complicated, and there are many factors influencing the final condition of the elements that should be considered in its lifecycle.

3. Case Study

The research was performed in the housing-estate Osiedle Przemysława which is located in Poznań (center of Poland), in the Antoniniek-Zielniec-Kobylepole area, between Chartowo (Osiedle Rusza) and Osiedle Zodiak in the west, and Kobylepole in the east. The estate's buildings extend along Folwarczna and (partly) Żelazna Streets. Figure 2 presents detailed location of the estate showing that Osiedle Przemysława is one of the most interesting housing location in Poland - very close to the green and recreational areas.

![Figure 1. Location of Osiedle Przemysława [11]; Figure 2. Visualization of analysed multi-family buildings [11]](image)

These objects are administrated by the The "Zrzeszeni" housing cooperative [12] which was established on November 20, 1987. The cooperative's resources include 432 apartments with a total area of 27,605 m², 9 commercial premises with a total area of 567,5 m² and garages with a total area of 1,282.9 m². The cooperative has 616 members.

Between 1988-1995, the cooperative realized on the area of 4.2 hectares, the "Przemysława" housing estate, which has been analyzed for the purpose of this article. These buildings, were one of the first in Poznań, were made in the technology of masonry walls with roofs covered with mansard tiles.

3.1. Research procedure

Authors for the purpose of the publication performed research which consisted of the following steps: preparatory actions, on-site visit, (detail check of handrails, balustrades, walls, concrete slabs, columns and flashings; interview with habitants), report preparation. In the course of work there were analyzed totally:
- 4 Buildings,
- 64 Apartments,
- 74 Balconies,
which allowed to draw the conclusions related to the actual condition of balconies and future actions required for performing proper repair process.

4. Analysis of results
There are presented detailed results and required actions on the analysed elements of the balconies which are illustrated with the pictures of discovered errors presenting actual state of the object after 20 years of normal usage. Based on the analysis each point presents also factors that were determined by the authors which influenced on the level of wear of the analysed objects.

4.1. Flashings

4.1.1. Actual condition. Condition of the flashings are illustrated in the following figures. Figure 2 presents problem related to extensive corrosion of metal elements. Figure 3 shows cracks and delamination of concrete declines as well as extensive biological corrosion, which is also available in Figure 4 with even bushes growing in concrete in Figure 5.

![Figure 2. Extensive corrosion of metal elements; Figure 3. Cracks and concrete delamination](image1)

![Figure 4. Extensive biological corrosion; Figure 5. Bushes growing in concrete declines](image2)

4.1.2. Actions required. Actions that should be performed are presented in Figure 6. They involve performing exchange of flashing elements in 18% of balconies and execution of maintenance processes related to biological corrosion in 61% analysed cases. It has to be noted that all balconies require some attention related to de flashings.
4.1.3. Causative factors. Based on the performed analysis authors deducts that effects observed during investigation were mainly caused by 2 factors which are lack of current maintenance and errors during execution of works in the construction phase of balconies.

4.2. Floors

4.2.1. Actual condition. Condition of the floors is illustrated in the following figures. It was observed that problems with floors involved biological corrosion of joints (Figure 7), tiles detachments (Figure 8) especially in the balconies on the last floor of the buildings and cracks, as well as execution errors i.e.: lack of levelness (Figure 9).

4.2.2. Actions required. Actions that should be performed to repair discovered issues are illustrated in Figure 10. 20% of balconies needs full repair processes including removal of tiles laying them again. 29% requires some minor corrections and repairs and 51% requires no action to be made, as the condition is sufficient for safe use.

4.2.3. Causative factors. Factors that caused such state of floors are mostly related to technical wear (age of the floor – almost 20 years), extreme environmental impacts (especially on last floors where there is no roofing) and lack of current maintenance. Authors note that not all of the floors had tiles installed, which is the result of housing cooperative policy, in which residents decide and pay for the finishing layer of the balconies on their premises.
4.3. **Concrete slabs**

4.3.1. **Actual condition.** Condition of concrete slabs is illustrated in the following figures. Figure 11 presents extensive corrosion of concrete at the edge of the slab which is a result of water penetration. Delamination od external layer of slab is also observed both in Figure 11 and 12. Figure 13 and 14 presents problem with cracks at the edge of the slab. This is probably caused by poor flashing execution. It is particularly dangerous, because concrete parts can separate and fall over the balconies and needs immediate attention.

4.3.2. **Actions required.** To fix problems with concrete slabs, 31% of the balconies needs serious construction repairs and 43% of them need superficial repairs in the plaster layer. Only 26% of analysed

![Figure 11. Corrosion of concrete slab at the edge](image1)
![Figure 12. Delamination of concrete caused by water penetrating into the slab](image2)

![Figure 13. Crack at the edge of the slab which results in concrete detachment;](image3)
![Figure 14. Crack at the edge of the slab.](image4)
balconies needs no action regarding repairs, so totally there are 74% of item that require attention and renovation.

![Concrete slabs diagram](image)

**Figure 15.** Actions that should be performed for concrete slabs repairs

4.3.3. *Causative factors.* Factors that probably caused such situation were manufacturing and design errors (too short hoods from sheets), as well as lack of proper maintenance. Cracks and delamination should be repaired on the regular basis to prevent further slab destruction. What is more, the maintenance would result in reduced repair costs for residents of the apartments.

4.4. *Concrete columns*

4.4.1. *Actual condition.* Condition of the concrete columns that has been checked was not ideal. The majority of columns had delamination of concrete present in the area of bottom part of it. Cracks are presented in Figure 16 and 17. What is more some horizontal crack has been observed in the columns on the top floor of the building (Figure 18). Water penetration and frost led to de-burgling the top layer of plaster and further detachment of plinth tiles (Figure 19).

![Delamination of concrete](image)

**Figure 16.** Delamination of concrete in the bottom part;  
**Figure 17.** Cracks and column plane curves

![Horizontal crack](image)

**Figure 18.** Horizontal crack on the top balcony;  
**Figure 19.** Water penetration and delamination of plaster layer.
4.4.2. Actions required. Actions that should be performed are presented in Figure 20. 13% of concrete columns requires construction repair and strengthening. 34% of the columns needs superficial repairs in the plaster layer. Only 34% of all analysed columns requires no actions to be taken to preserve its good condition.

![Concrete columns](image)

**Figure 20.** Actions that should be performed for concrete columns

4.4.3. Causative factors. Factors that caused this situation are related mainly to faulty solutions (flawlessness of the flanks causing damage at the interface) as well as wear and corrosion of concrete as a result of atmospheric interactions.

4.5. Metal balustrades

4.5.1. Actual condition. Condition of the metal balustrades are illustrated in Figures 21 and 22. It was observed that majority of balustrades were corroded. Some of them were broken and had some missing parts that influence on the safety of this elements. It has to be noted that 4 balconies had balustrade that were recently renovated and require no actions at all.

![Figure 21. Corrosion of all metal elements of the balustrades](image)

![Figure 22. Corrosion on the balustrade element](image)

4.5.2. Actions required. Actions that should be performed are presented in Figure 23. 77% percent of balustrades require cleansing and strengthening to ensure required proper level of safety for the end user. 18% needs renewal of paint coating and only 4% are in satisfying condition and requires no action.

4.5.3. Causative factors. Factors that caused such condition of metal balustrades are related to lack of correct maintenance, mediocre quality of designed solutions and impact of external environment conditions. It should be noted that the situation with missing parts of the balustrade should have never happened, since it directly influences on the safety of the residents.
4.6. Concrete balustrades

4.6.1. Actual condition. Condition of the concrete balustrades are the result mainly of water penetration. Illustration 24 and 25 presents paint delamination, extensive humidity and horizontal cracks that were observed during local vision.

4.6.2. Actions required. Actions that should be performed are presented in Figure 26. 1% of concrete balustrade needs to be rebuild. 49% needs superficial repairs in the plaster layer and 50% of all analysed balustrades requires no actions at all and are safe for further use.

4.6.3. Causative factors. Factors that caused present situation are as-built malfunction (no tight coverings of balustrades on the last floors), lack of maintenance, and natural consumption. It is advised that such elements should be observed and any noticed problems should be immediately repaired to avoid further destructions.
5. Conclusions

Performed analysis on the factors determining technical wear on the example of the analysis of the technical condition of balconies in multi-family housing prepared for the purpose of renovation works of the construction objects led to the following conclusions:

- Condition of analysed 74 balconies revealed that 95% of them require renovation actions to ensure safety further exploitation.
- Majority of observed effects are caused by the adverse external environment conditions especially penetrating water.
- Huge influence on the actual condition had errors that were made during design and execution phase of erecting of analysed structures.
- Proper maintenance is a key factor to prevent destruction of the elements which requires immediate reporting of irregularities noticed residents and can prevent from further destruction and excessive costs of performing needed repairs.

Authors are planning to perform further research on housing-estate Osiedle Przemysława that will involve technical analysis of other parts of the construction as well as building erected after year 2000 to compare its current state and to show what are the main differences in the condition of both type of structures.

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References

[1] Hannoudi L. A., Christensen J. E., and Lauring M., “Façade system for existing office buildings in Copenhagen”, *Energy Procedia*, vol. 78, pp. 937-942, 2015
[2] Milwicz R. and Pasławski J., „Comparative analysis of heating systems in terms of flexibility in sustainable buildings“, *Procedia Engineering*, vol. 208, pp. 82-89, 2017
[3] Zuhaib S., Hajdukiewicz M., Keane M. and Goggins J., “Facade modernisation for retrofitting existing buildings to achieve nearly zero energy buildings”, *Structures and Architecture – Cruz (Ed)*, pp. 599-606, 2016
[4] Monzón M., and López-Mesa B., “Buildings performance indicators to prioritise multi-family housing renovations”, *Sustainable Cities and Society*, vol. 38, pp 109-122, 2017
[5] Martinez A., Patterson M., Carlson A., and Noble D. “Fundamentals in Façade Retrofit Practice. *Procedia engineering* vol. 118 pp. 934-941, 2015
[6] Kamari A., Corrao R., and Kirkegaard P. H., “Sustainability focused decision-making in building renovation”. *International Journal of Sustainable Built Environment*, vol 6(2), pp.330-350, 2017
[7] Pasławski J., “Flexible Approach for Construction Process Management Under Risk and Uncertainty”, *Procedia Engineering*, vol. 208, pp. 114-124, 2017
[8] Rokiel M., „ABC Tarasów i Balkonów. Poradnik eksperta”, DW Medium, 2015
[9] Rokiel M., „Tarasy i balkony. Projektowanie i warunki techniczne wykonania i odbioru robót”, DW Medium, 2012.
[10] Dubas S., Pasławski J., „The concept of improving communication in BIM during transfer to operation phase on the Polish market”, *Procedia Engineering*, vol. 208, pp.14-19, 2017
[11] http://maps.google.pl/maps, Google street view, access 28.03.2018
[12] http://www.spoldzielniemieszkaniowe.pl/main/spoldzielnia-mieszkaniovazrzeszeni,149,236,.html access 28.03.2018