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Analysis of errors in restoration of salty and damp walls

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***Abstract*- This paper presents the study of the most common errors made in the restoration of salty and damp masonry structures. Analysis of the errors was based on site visits to 127 facilities where restoration treatment was carried out. A set of technical and technological activities aimed at permanent reduction of the moisture level in walls, usually to 3 - 6 percent of mass humidity, was evaluated in terms of correctness if their implementation. These activities included treatments related to the implementation of damp-proof membranes and a whole set of activities involving new sanitary, heating, electrical, ventilation or air conditioning installations, clearing of obstructions or changing rainwater drainage. Errors were studied in three areas: design, construction and usage. It was found that the basic errors arising during the building drying process are errors at the design stage, followed by construction and usage errors.**

Keywords—r*estoration of monuments, rehabilitation of buildings, drying of damp buildings*

I. Introduction

In recent decades, the approach to the restoration of buildings was changing considerably. In the past, the main renovations were closely related to the purpose of a building. Any renovation treatments were carried out only when a building was expanded or converted to perform new functions. Modern societies are aware of the need to preserve buildings of historical interest. They represent a cultural heritage which should be eternal. The task of the present generation is to preserve this heritage in good condition for future generations. This act of culture presents engineers with high challenges. European countries have gained great experience in the restoration and conservation of objects of historical value. In recent years, substantial resources were spent for the development of non-destructive testing, monitoring and structural analysis of historical buildings [1,2].

Restoration of masonry structures is of particular importance in this respect. The rapid development of modern renovation technology, modern facilities monitoring methods and, above all, modern building materials create new opportunities for all actors involved in the preservation of cultural heritage. Modern methods of monitoring in this area are intensively developed by Prof. J. Juraszek [3-8]. They are based on fiber optic technologies such as FBG (Fiber Bragg Grating) and OTDR (Optical Time Domain Reflectometry). They enable continuous measurement of strain, displacement and temperature in the important areas of the structure. They represent a sort of intelligent monitoring system. Nevertheless, there are many examples showing lack of success in conducting restoration treatments. Proper renovation of such structures requires a combination of advanced engineering knowledge with highly competent analysts, using specialist equipment in their work [9].

In the renovation of buildings of historical importance, a common cause of damage is poorly functioning horizontal and vertical wall insulation. Moisture is transferred from the ground to the wall through their porous structure as a result of capillary rise. In removing the consequences caused by capillary water rise, the best results are obtained by using complex methods, involving physical or chemical restoration of moisture barrier and drying and desalting damp walls. The chemicals used in the chemical injection change the surface properties of the pores, resulting in stopping the water rise process. Then, above such diaphragm, the zone of reduced mass humidity appears. In order to accelerate the drying of a wall non-invasive methods of drying and restoration plasters are used for diverse sizes of pores [10, 11].

The paper presents a study of the most common errors in the renovation of saline and damp masonry structures based on the cases from the practice. The study concerns a set of technical and technological activities aimed at permanent reduction of the moisture level in walls, usually to 3 - 6 percent of mass humidity. These activities include treatments related to the implementation of damp-proof membranes leading to lowering wall humidity and a whole set of activities involving new sanitary, heating, electrical, ventilation or air conditioning installations, clearing of obstructions or changing rainwater drainage, and finally re-profiling of the surrounding area. Errors and omissions in building drying may occur at three levels: design, construction and usage.

The analysis carried out in this paper will contribute to the development of science in the discipline of construction and should provide a foundation for theoretical knowledge that enables better achievement of the renovation objectives.

II. Background

Mistakes made in the restoration of damp walls are of different origins. In order to create the proper context for interpreting of observations, an analysis of expert opinion was carried out. The analysis was carried out in terms of: correctness of restoration design, the assessment of the quality

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of the works, evaluation of the materials used, inspections and determining whether no effects, different from those adopted in the project, occurred. On this basis, three main levels on which errors are made were established.

A. ***Design errors***

The most frequent error at the design stage of the renovation of saline and damp walls is omitting a thorough and comprehensive assessment of the cause. In order to minimize the costs of design services, designers abandon costly expert evaluations. Therefore, what is necessary to determine the correctness of the technological solutions, is often designed "at a guess."

At each stage of diagnosis there may be potential difficulties resulting in the wrong conclusions. Depending on the diagnostic procedure the following problems may occur:

historical analysis - specifying, on the basis of preserved documents, how the building was built and the type of its foundation. In historic buildings the contour of foundations is most often not distinctly separated. The preserved design documents most often, the outline of the basement wall thickness is shown, and you can rarely see strip footing with offset pr expanding linearly obliquely towards the bottom edge of the foundation. In some buildings indirect foundation on stakes or wooden grids are dominant. Their occurrence determines the possibility of surface or band drainage around the object.

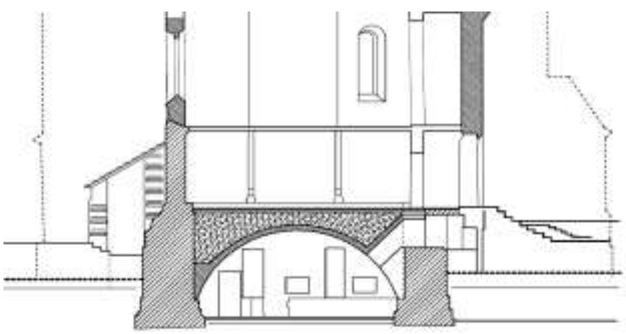

Figure 1. Cross section of a medieval stone church in Wroclaw (Poland), different shape and contour of the foundation in relation to the main body of the church is visible.

interview the owner or administrator - a common cause of mistaken diagnosis is insufficient knowledge of the changes in water and soil conditions. In the vicinity of the historical foundations the parameters of the ground often change affecting its carrying capacity. A common cause of loosening the subsoil can be dry wells placed in the immediate vicinity, reconstruction or expansion as well as changes of the usage.

uncoverings - too little uncoverings may also cause errors. Uncoverings are necessary to determine whether the building's foundations are not flooded by groundwater, and sometimes it is the only way to determine the level of foundation. Uncovering also allow to determine the condition of the basement walls. Often, uncovering eventually exclude or confirm the necessity of external band drainage or replacing the soil

determining the degree dampness and salinity - the degree of dampness of the walls has a decisive influence on the how to restore isolation, on the type of restoration plaster used and on the way harmful salt crystallizes on the faces of the walls. Frequent cause of errors is the measurement method. The most common are measurements using detectors (surface) which, with significant salinity of walls, provide approximate results only. In order to avoid errors, if you the most accurate drying and weighting method is not used, the results of measurements should be compared with a carbide meter (CM method).

determination of the wall structure - an element necessary to examine the structure of the walls is performing drillings at different heights. In the past, brick was a relatively expensive material, far more expensive than it is now. The consequence was building 'beggar' walls in which the stem was made of less expensive materials. Bricks were only used for the facing wall layer. In the walls of historic buildings the very method of their construction, the type of material, and many centuries of effort caused the development of a variety of irregular voids, caverns and stretch marks. Test drillings may confirm the necessity of initial injections e.g. of low-shrinkage trass mortars in the divisions. This is the basic condition (both for pressure and non-pressure injection) for properly restoring the horizontal diaphragms. Low-pressure injections within the walls with voids result in a given standardized amount of injected product not filling properly the injection holes.

Figure 2. Appearance of the exposed foundation walls of different construction.

analysis of ground and water conditions - proper design of drainage around the building should be preceded by hydrogeological studies aimed at defining the water and soil conditions around the building. This investigation enables, among others, proper design of drainage around the object. In city centers, next to the existing historic buildings, new ones with highly developed underground part, intended e.g. for multi-level garages, are built. These buildings are designed

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and built completely independent from each other, leading to the formation of clusters and strings of underground compartments which, in an uncontrolled manner, interfere with the natural hydrographic conditions. The current investment activity in urban centers is conducted in a manner which ignores important geotechnical and hydrogeological conditions. Deep underground floors pose a threat of ground water accumulation or change in the direction of their runoff. Designers of newly erected buildings do not take into account potential impacts on the hydrogeological conditions sometimes in a considerable area around the erected building.

Fig. 3. Moisture level of the northern wall reaches approx. 5 m high above ground level - Museum in Raciborz.

B. *Construction errors*

Construction errors are divided into those that absolutely must be removed, and those which, under certain conditions, may remain. The most common construction errors include:

Shortening the designed cycle of the technological process- in the restoration of damp walls, shortening the technological cycle may lead to discontinuities in moisture barrier formed by chemical injection and result in errors causing maintaining high humidity of walls after restoration. The most common errors are too high pressure in the pressure injection, which disturbs the structure resulting in the leakage of the injected formulation outside face of the wall in which the diaphragm is made. Another error is using less injection fluid per unit of cross section of the partition than recommended by the designer. The persistence of very high wall humidity after restoration may be the result of shortening the technological periods necessary for the diffusion of moisture from the wall, as well as reducing the prescribed quantity or thickness of individual restoration plaster layers.

No control over wall humidity before, during and after the work- the contractors and investor supervision often do not have the data necessary to create documentation based on which the proper performance of the moisture membranes could be assessed. During the injection, it is necessary to control the mass humidity changes of the walls, and each hole should be recorded on pre-prepared sheets, stating the type of waterproofing agent used, its amount resulting from the thickness of the wall, the time of injection, the injection date and the signature of the employee. Attached to the sheet should be a survey sketch defining the room number and its location on the projection of the insulated floor.

Discontinuity of horizontal moisture barrier - the most common cause is too small injection hole spacing, other than specified in the design, as well as using improper injection formulations, e.g. cheaper substitutes.

No color uniformity in place of the block-it often turns out that only after the injection holes are made and finally filled with trass mortars, the decision to merge the color of the facade is taken. Due to the nature of works, the location of the holes should be agreed with the architect at the stage of designing colors for the building.

Failure to prepare and complete post-completion documentation- during excavations, all sorts of buried remains of foundations of buildings that no longer exist or various unmarked installations often hinder the excavations and later the insulation. It is then necessary, in consultation with the designer, to set the new injection shut-offs to correctly secure the proper wall.

Vertical isolation in places of connections is omitted or there is improper sealing of new installation in places where it passes through external walls- the most common cause leading to leaks of the waterproofing barrier is incompetent insulation of elements intersecting foundation walls. The most appropriate solution is to adopt a systemic solution recommended by the manufacturer of the insulation used.

C. *Usage errors*

The basic usage errors include:

- *Failure to carry out periodic facility inspections.*
- *Negligence due to the lack of ongoing maintenance.*
- *Errors due this ignorance of the owner or administrator.*

A common cause of errors is the failure to take into account the works to be done in the next stage of restoration in the design stage. These relate primarily to improving the operation of existing ventilation, proper drainage of rainwater, using paints to paint renovating plasters, etc. In this group also includes errors which the contractor cannot influence and which are associated with low awareness of the user of the building to be dried. Final results of restoration of damp building can be seen only after a few years of completion of the works. Proper usage is also an important factor in assuring the comfort of the rooms.

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III. Discussion

Analysis of the errors was based on site visits to 127 facilities where restoration treatment was carried out. 38 expert reports were analyzed in order to determine the causes of deterioration of the technical condition after renovation. Only the facilities in which there were problems with capillary moisture were studied. Restoration treatments were carried out between 2007 and 2013. Among those buildings 29 were built in the period from the 15th to the 18th century and 98 were built in the 19th century. The number of buildings undergoing restoration in each year was varied and ranged from 15 to 20. Specific numbers of restorations carried out in different years are presented in Table 1. On the basis of the criteria adopted in section II, errors identified in the analysis were assigned to one of three predetermined groups. Generic summary of errors in individual years is presented in Table 1.

TABLE I

Error category	Year of restoration						
	2007	2008	2009	2010	2011	20012	2012
Design errors	7	5	4	3	2	3	1
Construction errors	13	9	7	5	4	4	3
Usage errors	1	2	3	1	2	1	2
Number of restorations	17	16	14	15	16	19	15

A graphic representation of the error dynamics in individual years is shown in the graph, Figure 4.

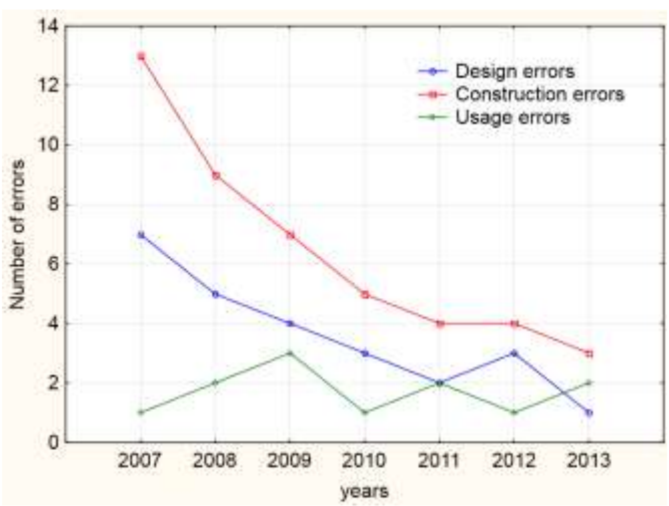

Figure 4. Graphical presentation of errors in the restoration of damp walls in the years from 2007 to 2012.

Analyzing the chart in Figure 4 we can say that with as years go by the dynamics of design and construction errors decreases. Particular intensification of errors was observed in the years from 2007 to 2010. In subsequent years the number of errors is lower and lower. This shows an increase in technical awareness among both the designers and contractors. Knowledge and experience gained by the technical and engineering staff results in reduced number of restoration errors.

Analyzing the structure of errors in individual years can be said that most errors occurred at the construction level. It was observed that in most cases the presence of design errors entailed construction errors. A common cause of this phenomenon was incorrectly executed design documentation, together with the technical specification of execution and acceptance of works. "Incompatibility" of investors' expectations with their abilities to finance the investment was also an important factor. The case was often that at the time design concept was to be approved together with the cost estimates, the scope of works had to be limited due to insufficient financial resources of the investor.

Most design and construction errors were recorded when changing the functions of cellars that were neglected for decades. Because of the need to maintain operational parameters it was necessary to reduce the floor level, which was connected with the need to raise the existing foundations. In such cases the works were limited only to restoring no longer existing or degraded insulation, and lowering humidity barriers above the planned waterproofing membranes. Due to the high costs, treatments aimed at reducing the existing groundwater levels, involving establishing surface and band drainage, were abandoned.

A technological activity virtually overlooked at the insulation design stage in historic buildings was making a preliminary internal sealing of all voids, caverns and gaps in the insulated partitions. This has resulted in discontinuities of the designed insulation. Such sealing, called initial injection, should be performed at low pressure, using mortars low-shrink trass mortars. In order not to hinder the propagation of the hydrophobic formulation at the proper application, the degree of permeability of the injected agent for such mortar must be similar to the permeability coefficient of the wall. Initial injection should always be used for layered historic walls or walls with stone face cladding.

The modern standard in restoration of damp walls is non-destructive drying of walls after implementing hydrophobic barriers. The most effective form of such water removal from above the diaphragms is the simultaneous use of desiccant dryers in combination with microwave drying. The detailed design, in addition to determining the exact method of lowering the walls moisture level, should contain information on the necessary technological break needed to perform this action. A common error was not determining the intensity of the drying process. The design should state the temperature to which dried walls can be heated in one cycle. This is necessary to avoid thermal stress at the brick-to-mortar interface that could exceed their strength parameters, or destroy the mortar itself.

It often happened that the contractor, despite prior agreements with the user, has no influence on the user's further actions. An example would be painting renovating plasters in the basement of a building with oil paints, which consequently led to the need for further renovations. In another case, after renovation, the owner of the building carried out further

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repairs involving the replacement of electrical installation. Grooves carved in renovating plasters were filled with gypsum mortar. After re-painting the walls, the whole installation layout was visible. A common mistake of the owners was also poor care for sufficient ventilation of rooms. In many cases, the air grates were veiled or blocked with furniture. Consequently, this has led to the emergence of the house or moldy fungus [12].

Fig. 5. The fruiting body of the house fungus proper (Serpulla lacrymans), grown into a vaulted ceiling of a basement room

Many design errors could have been prevented at the stage of implementing restoration treatments. In many cases investor supervision failed, not reacting in face of situations unforeseen in the design. Often, when walls were exposed, unsurveyed sewer or rainwater systems were found, hindering excavations. Such cases were not reported to investors as an additional scope of works associated with the need to replace or unblock them. Often, the work was limited to partial replacement of horizontal pipe sections across the width of the excavation. Sometimes such drains were left unblocked.

IV. Conclusions

The basic errors arising during the building drying process are errors at the design stage, followed by construction and usage errors. Certain groups of mistakes and omissions repeat constantly and include primarily:

- Preparation of project documentation without the prior reliable diagnosis on the basis of which drying should be completed,
- No comprehensiveness of actions and solutions at every stage,
- Abandoning part of the technological activities during the construction, causing a reduction in the expected sustainability of corrective actions.

A common problem is the lack of user awareness when it comes to the need to drying the building. The user should know that this is an important process that makes a facility no longer to be categorized under the "sick building syndrome"

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