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## DESCRIPTION OF TECHNOLOGICAL AND ORGANISATIONAL PROBLEMS IN CONSTRUCTION WORKS USING THE EXAMPLE OF RESTORATION OF THE OUTER COURTYARD ON WAWEL HILL

### PROBLEMY TECHNOLOGICZNO-ORGANIZACYJNE ROBÓT BUDOWLANYCH NA PRZYKŁADZIE REWALORYZACJI DZIEDZIŃCA ZEWNĘTRZNEGO NA WAWELU

#### Abstract

The paper discusses the process of restoration of the outer courtyard on Wawel Hill, which was part of a project co-funded by the European Union under the “Infrastructure and Environment” programme. The location and specificity of the restoration works generated many technological and organisational problems during their implementation (most of which could not have been predicted earlier), which in turn determined the different approaches and concepts available for solving them. The article is therefore a kind of case study, which demonstrates the specific implementation al problems associated with this project, as well as identifying the mistakes to be avoided, on one hand, as well as to point to concepts which are worth repeating..

*Keywords: technology, construction plan, restoration of historical monuments*

#### Streszczenie

W artykule omówiono proces rewitalizacji dziedzińca zewnętrznego na Wawelu, który był częścią projektu współfinansowanego ze środków Unii Europejskiej w ramach programu „Infrastruktura i Środowisko”. Miejsce oraz specyfika realizowanych prac rewitalizacyjnych generowały na ich etapie wiele problemów technologiczno-organizacyjnych (w większości niedających się wcześniej przewidzieć), które z kolei determinowały różne podejścia i koncepcje ich rozwiązywania. Artykuł jest więc swoistym studium przypadku, które pozwoli nie tylko na poznanie specyfiki problemów realizacyjnych wspomnianego przedsięwzięcia, ale także na wskazanie z jednej strony błędów, których należy unikać, z drugiej zaś, wskazanie koncepcji wartych skopiowania.

*Słowa kluczowe: technologia, organizacja robót budowlanych, rewitalizacja zabytków*

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## 1. Introduction

Construction works are a collection of construction processes, which include interconnected construction, technological and organisational operations and tasks, forming the basis for achieving the desired objective, which is to build a new structure, renovate an existing one, or carry out a demolition [1]. Properly selected factors of production (labour, materials and equipment) and high technological quality of building components are necessary for ensuring a smooth construction process. However, during the execution of the works there may be some unexpected situations, in the face of which it is necessary to change the previously scheduled technology and construction plan. Technological and organisational problems during construction works are therefore one of the key issues faced by the contractor at the implementation stage of the works.

While the deterministic nature of construction works leading to the creation of a new structure favours, at the time of their execution, the immutability of the previously planned technology and construction plan, in the case of a process associated with the restoration of a historic facility one must reckon with continuous change of this technology and construction plan. The unpredictability of the process of restoration is mainly due to the fact that we are dealing with historical material, which is not only building material that must be well examined in technical terms, but also is a carrier of certain cultural values. During the restoration process, situations can often occur, which were impossible to predict at the design stage, and are related, for example, with an archaeological discovery, which may lead to a change in the planning and execution of works, as it may be a consequence of the introduction of the so-called variation works or extra works. In any case, the decision for choosing the right technology and construction plan should be supported by a thorough, often multi-criteria, analysis, taking the restrictive conditions resulting from the circumstances and specificity of ongoing work into account [2, 3].

The purpose of this article is firstly to present the technological and organisational problems arising during the execution of works related to the renovation of the Outer Courtyard on Wawel Hill, along with access roads, and then to draw conclusions and offer guidance which should help in avoiding such problems in similar projects carried out in the future.

## 2. Objectives of restoration and its scope

Restoration of the outer courtyard on Wawel Hill along with access roads was part of the “Framework Work Plan on Wawel Hill for Years 2004–2010” carried out by the Royal Castle on Wawel Hill. This restoration was necessary due to the deteriorating state of the stone surfaces in the Outer Courtyard and access roads as well as the poor condition of underground infrastructure (water supply, sewerage, electrical, fire protection, and telecommunications networks). An additional objective of the restoration was to improve and reorganise circulation routes for tourist, ensuring access for people with disabilities. Improving the condition of historical monuments and enhancing the quality of services for domestic and foreign tourists as part of the popularisation of world cultural heritage made it possible to qualify this projects to Priority XI Operational Programme Infrastructure and Environment, Action 11.1 “Protection and Preservation of Cultural Heritage of Supra-Regional Importance”.

Restoration of the outer courtyard and access roads (Fig. 1), included the following tasks:

- 1) replacement of underground infrastructure (water supply, sewerage, electrical, fire protection, and telecommunications networks),

- 2) comprehensive replacement of paved surfaces (about 10,000 m<sup>2</sup>) with the reconstruction of outdoor stairs and the construction of a driveway and ramps for the disabled,
- 3) reconstruction of the stone toe wall along a pedestrian path and other landscaping elements,
- 4) construction of reinforcement and insulation of crownwork (old Austrian fortifications),
- 5) construction of irrigation systems for green areas.

All works were carried out under the strict archaeological supervision and the entire project was supervised by a conservation officer.

a)



b)



Fig. 1. View of a part of the outer courtyard along with access roads on Wawel Hill: a) during renovations, b) after renovations (source: Royal Castle on Wawel Hill archives)

### 3. Key factors generating technological and organisation problems during construction works

#### 3.1. Uncertainties during the design stage

The basis for the proper restorative design of a historical monument requires in depth information about it (its past and existing state) and to analyse the conditions associated with the monument. However, in the case of historical monuments, the information gained by the designer during the survey is subject to a high degree of uncertainty, during the course of which design decisions can lead to varying results due to the occurrence of events, the likelihood of which are not known.

In the case of this project, uncertainty of information related to:

- Geotechnical parameters of the existing subsoil. The upper soil layers on Wawel Hill are in fact to a greater extent mixed with man-made fills (fills resulting from the rubble of demolished buildings, debris, ash and topsoil). This heterogeneity of the subsoil is difficult to verify, despite the implementation of test boring during the survey;
- The exact route and depth of existing underground infrastructure (routes of electrical, telecommunications, water supply, sewage and fire protection networks as well as other networks, which are not subject to repair, but which could come into conflict with the planned infrastructure.) Despite having access to the current site maps, inconsistencies of

the location of underground infrastructure, which over the decades has been rebuilt many times, could not have been ruled out;

- The number of and exact location of archaeological relics from the old buildings on the Wawel Hill. Currently, although this cannot be seen directly, Wawel Hill is the largest active archaeological dig in Poland, where objects of historical interest are being found with a varying frequency on an ongoing basis;
- The technical condition of underground structures such as the “Rabsztyn” archaeological reserve, the foundations of crownwork fortifications and others.

All of the uncertainties listed above mean that the technical solutions developed by the designer might not meet expectations at the implementation stage in the face of situations that were previously impossible to predict, which in turn will determine frequent design changes to achieve appropriate solutions, which will not always be possible to implement using the originally adopted technology and plan of work.

### 3.2. Limitations associated with the specificity and function of the structure and its surroundings

Basic limitations in this project include:

- A ban on the use of vibratory rollers for compaction of bedding layers of the renovated surface due to the protection of historic materials from adverse vibration;
- Limit on the use of heavy earth-moving equipment because of the
- potential archaeological finds;
- Constant archaeological supervision during the execution of earthworks;
- Limit on the use of heavy equipment for demolition due to the expected maximum recovery of stone materials from demolished pavement;
- Carrying out the works during constant tourist traffic (in an active facility) and interruption of the work for the visits of state and foreign delegations;
- Replacement of all underground infrastructure, ensuring continuity in the provision of utilities to open museum buildings (the need for bypasses);
- Restrictions on the movement of contractor’s vehicles due to the safety of tourists and museum workers;
- Ensuring access for fire fighters and other services to the Wawel Hill buildings;
- Limited space for storage of building materials including those from demolition;
- Dependence of the work on changing weather conditions (three winter periods);
- Implementation of work in stages (division of the restoration into 12 stages).

## 4. Selected technological and organisational problems

### 4.1. Problems with the selection of shoring

Originally, the shoring technology for narrow excavations adopted by the contractor for the construction of a new sewerage system was based on the use of steel form work systems. Although this type of shoring installed in the excavation required the use of heavy equipment,

this method allowed the contractor to maintain a high pace of work at relatively low cost of labour needed for its execution. However, during the course of the work it was found that this shoring technology could be used only in reopened excavations (i.e. on the route of the old sewerage network). In a situations when the route of the new sewerage network did not overlap with the existing one, the archaeological supervision forced the contractor to change the method of securing excavation walls using a (traditional) skeleton sheeting method (Fig. 2).



Fig. 2. Method of securing excavation walls: a) for reopened excavations b) for new excavations, with prior archaeological reconnaissance (source: Royal Castle on Wawel Hill archives)

This change in shoring technology allowed archaeologists access to the side walls of the excavation and provided the opportunity to carry out a complete analysis of the stratigraphy of archaeological layers which had not yet been investigated on the new route of excavations. Unfortunately, from the contractor's point, changing the method of shoring the excavations generated much higher labour costs, heavy and costly wood consumption and unfortunately prolonged the time required for this type of work.

#### 4.2. Problems with the producibility of alternative solutions

Another example of the technological and organisational problems was associated with the strength of the subsoil during the construction of the pavement in the outer courtyard and on access roads. After constructing the roadbed and before laying geotextile and reinforcement geogrid and subgrade layers, an obligatory task was to check proper compaction had taken place at the bottom of the roadbed, and to compare these results with the design requirements. A static plate load tester was used to test the strength and in difficult to reach places, using a deflectometer. However, it turned out that the results differed significantly from the expected values. First, the contractor decided to try to use the current, planned method of reinforcing the weak subgrade using said geogrid. In order to minimise the expenditures on labour and equipment, it was decided to construct a 25 sq.m. trial plot, on which the contractor placed a layer of geotextile, geogrid and then two bedding layers made using aggregate with a grain size

of 31.5 mm. However, the attempt to achieve the required strength at the level of the supporting bedding failed. Unfortunately, the replacement of the soil in order to improve its strength or its stabilisation using hydraulic binder as well as the attempt to improve soil gradation was not possible for archaeological reasons. As a consequence, it was decided to lay a geocell, i.e. a spatial system made of polyethylene tape in two layers, with a thickness of 20 cm each, with filling the space between “cells” using aggregate with a grain size of 31.5 (Fig. 3).

a)



b)



Fig. 3. Methods of strengthening weak soil: a) in the lower left corner the originally designed strengthening using geogrid can be seen, b) The said geocell (source: Royal Castle on Wawel Hill archives)

After the test on the trial plot, strength tests were carried out again, and this time results reached the designed value. Changing the method of strengthening the subgrade caused an increase in expenditures on labour and equipment as well as the execution time of one sq. m. of such reinforcement took much longer, not including the time needed to train workers for whom this solution was new. This spatial structure had to be laid manually. The method of compacting each layer of the geocell required the prior laying of a 5 cm layer of aggregate, whose task was to secure the top part of the geocell from mechanical damage due to rolling. After compacting and execution of verification tests, the protective layer had to be removed in order to implement another geocell layer. Thus, the level of producibility of the above solution meant that the implementation of such reinforcement was not easy in the existing production conditions.

#### 4.3. Problems with the selection of demolition technology

The contractor’s decision as to the selection of the right technology and construction plan was supported by a thorough analysis, taking the restrictive conditions resulting from the circumstances and specificity of ongoing work into account. It often happens that the originally adopted concept for a given operation proves to be suboptimal, generating an unnecessarily large workload. In this restoration project, one of the operations was to dismantle the wear course made of large stone slabs on the existing surface. In accordance with the guidelines of the conservation officer, the sandstone slabs after removal had to be evaluated for the possibility

of their re-installation. This approach (the idea of maximum recovery of material) determined the need for their careful dismantling and moving onto hauling equipment, in order to take them to a place of possible further treatment. Attempting to manually disassemble slabs and their transfer to the designated place quickly proved to be inefficient due to heavy labour intensity, the consequence of which was the low efficiency of this operation. The large area of removed surface stone (over 4,500 sq. m.), the high cost of labour and time regime, demanded an immediate change of the technology and work plan through the use of special machines, whose pneumatic fittings allowed careful removal of stone slabs and efficient transfer onto hauling equipment. The investment in specialised equipment gave contractor tangible benefits in the form of high efficiency and much lower labour costs, and in the long term the equipment proved to be invaluable when laying new pavement (Fig. 4).



Fig. 4. Methods of dismantling stone slabs: a) Manual b) Mechanical  
(source: Royal Castle on Wawel Hill archives)

#### 4.4. Problems with planning construction work

Restoration works had to be carried out with constant tourist traffic and for the entire duration of the renovation it was necessary to ensure access for fire fighters and other services to Wawel Hill buildings. To meet these demands, the entire project has been divided into 12 stages, the order of implementation of which was strictly specified in the baseline schedule. The division of the project into stages resulted in a lack of continuity in the performance of similar construction processes and uneven demand for means of production as well as problems in the planning of employment (Fig. 5).

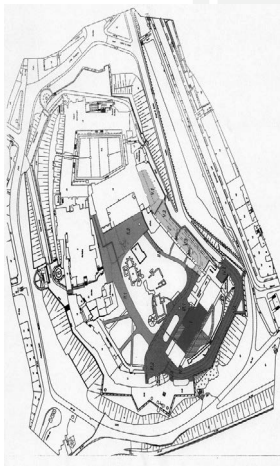
### 5. Conclusions from the case study

The analysis of the restoration case above allowed the authors to draw conclusions and propose (Table 1) guidelines, allowing contractors to avoid or reduce the risk of technological and organisational problems in similar future endeavours.

**Factors generating technological and organisational problems and proposals to avoid or reduce these problems (source: own work)**

Factors generating technological and organisational problems in construction works	Guidelines for contractors allowing to avoid or reduce technological and organisational problems in construction works
Uncertainties arising from the weak reconnaissance of soil and water conditions, location of underground archaeological relics, routes and depth of existing underground infrastructure	As far as possible, the implementation of the so-called proactive actions (local test pits) to identify soil conditions, locate underground facilities and in consultation with the archaeological supervision, the believed location of archaeological relics
Possibility of extra works and varied works during construction	Providing skilled workers, and possibly universal equipment to efficiently adapt to changes of the producibility of building solutions
Archaeological and conservation restrictions related to the use of heavy equipment to carry out demolition, earthworks and surfacing	Providing small-sized equipment (e.g. compact excavators, small rollers (static), etc.) and taking into account (in the cost estimate and schedule) the possible need to perform certain works manually.
Execution of works in an active facility and the resulting limitations	Implementation and ongoing updating of detailed construction plans and traffic management plans and ensuring high safety culture

a)



b)



Fig. 5. a) Plan of renovation stages, b) Fire fighter exercises during construction works (source: Royal Castle on Wawel Hill archives)



## 6. Conclusions

Restoration of the outer courtyard on Wawel Hill along with access roads was a difficult undertaking. Complex works carried out over a large area, interfering with historical materials, implemented over a protracted period of time (30 months) generated technological and organisational problems. The guidelines proposed in the article (Table 1), may be helpful in avoiding or reducing the occurrence of such problems in similar future endeavours.

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