

EVOLUTION OF METHODOLOGY OF PREPARING DATA FOR SETTING-OUT AND FINAL CHECKING OF CONSTRUCTIONS OF COMPLEX SHAPES

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INTRODUCTION

The presented paper has been inspired by practical achievements of the Warsaw Surveying Company (WPG SA) in the course of implementation of constructions which may be considered as „difficult” from architectural point of view; those practical works concerned the complete surveying services performed at each stage of development of those constructions.

Such constructions are characterised by the geometrically untypical and complex shape of the external body, by the unique construction and big volumes.

The authors presented their experiences basing on results which have need gained in the field of the applied methodology, starting from the stage of the design preparation, data preparation for setting-out, development of setting-out technology within the space of untypical constructions, maintenance of the, so-called, „duty map” of typical elements, as well as at the stage of the final checking of the constructed part of the structure and obtained accuracy level.

Conclusions being the results of those experiences have been presented basing on the following, practical works:

- The Świętokrzyski and Siekierkowski Bridges in Warszawa
- The Sucharski Bridge in Gdańsk
- The Office Buildings: Holland Park, WFC, Westin and InterContinental Hotels
- The Office and Trade Complex „Golden Terraces” in Warszawa.

An independent aspect, which is discussed in this paper, is the presentation of modern rules of surveyor’s work and his measurement facilities, while contacting the investor and his contracting unit, i.e. the building company, which implements the given investment. Those rules are not based on common schemes, but they are often worked out on the *ad hoc* basis, using the modern procedures, which are practically implemented at the construction site.

Besides, the paper presents untypical solutions, which may be considered as patterns in case of surveying works, performed for the needs of important, contemporary, brave architectural designs in Poland.

This refers to techniques, technology of services and required accuracy levels with the use of the most modern surveying instruments applied by surveyors, with the particular respect to:

- Formal procedures at the stage of investment preparations (acquisition of building permits / maps for legal purposes, maps for designing needs,

- **Combination of the investment designs with maps for designing purposes with respect to design matching into the existing surroundings, basing on spatial data for the given area,**
- **Planning of monitoring cycles for all phases of planned investments; from excavations for foundations, through implementation of the “zero” level and development of monitoring documentations for surrounding constructions,**
- **Permanent inspection of the design by preparation of data for setting-out, setting-out and inventory after setting-out at all intermediate stages of the given investment (basing on the main axes),**
- **Monitoring of settlement, control of verticality and construction geometry basing on the assumed realisation network,**
- **Investigation of accuracy of location of forms and post-implementation checking of construction elements after disassembly works,**
- **Post-implementation inventory of the investment, at the stage of its transfer by the investor to exploitation,**
- **Monitoring of the investment (basing on surveying cycles) after its transfer to exploitation,**
- **Archiving surveying data, which document all stages of the design and its implementation.**

Due to limited possibilities of presentation, only selected aspects have been discussed out of the above list, basing on existing practical experiences.

CLASSIFICATION OF MAPS FOR DESIGNING PURPOSES, DEPENDING ON DEMANDS OF DESIGNING OFFICES

In practice, the evolutionary cycle in the process of utilisation of maps for designing purposes may be observed: transfer from analogue to digital forms. This naturally results in diversified approach of a surveyor to the task of preparation – within a time sequence – of the data type required for the investment implementation process. However, in the majority of cases, leading building companies assume a digital map, not in the 2D version, but in the 3D version, as a standard; implementation of the building design of the Golden Terraces proved that such an approach becomes the common approach at present. In this case the American designing company required the 3D inventory of surroundings of the developed construction; this requirement concerned the Central Railway Station including the entire system of underground infrastructure. It is difficult to discuss benefits resulting from the described approach, but conclusions are very straightforward: one spatial reference system is applied, which is based on legally binding standards concerning data exchange formats in geodesy, which have been considered as approved standards for building designs.

CLASSIFICATION OF DESIGNING DOCUMENTATION

The existing designing documentation usually consists of:

- **the architectural design,**
- **constructional designs, which include:**
 - a. **Collective designs, horizontal projections, vertical projections of constructions,**
 - b. **Detailed designs of constructions,**
 - c. **Designs of constructional elements.**

That documentation is transferred for implementation in the form of drawings or in the digital form, depending on the nature of performed designing works.

In the case when:

- „the drawing design” exists
 - An object is located basing on details or reference lines,
- „the digital design” exists
 - An object is located basing on specified object co-ordinates,
- „the digital design on a digital map for the designing purposes” exists
 - An object is immediately located (at present, this situation often happens in the case of complex road systems); this may be confirmed by works carried out in co-operation between the WPG SA and Transprojekt Gdańsk Company.

It should be noticed that – in the process of utilisation of maps for designing purposes, submitted by surveyors in analogue or digital forms - almost all designing offices develop their designing works using various versions of the AutoCAD software tools.

For example: in the case of implementation of the Golden Terraces design, the map developed for designing purposes in the 3D version allowed the designers to combine the planned investment with the complex structure of surrounding constructions – mainly with technical infrastructure and underground installations (utilities). The entire design was performed basing on the realisation network matched with the geodetic network in the town co-ordinate systems (error after adjustment $m_p = 1.5\text{mm}$); as a result, after location of main axes has been submitted by designers, drawings of the construction, developed using the AutoCAD, were matched into the town co-ordinate system. Therefore data acquired from the design in the form of co-ordinates, were immediately ready for setting-out purposes.

The historical outline for the adopted methodology was as follows:

- The Holland Park located close to the Three Crosses Square in Warsaw (constructed in 1997). The digital map for designing purposes developed with the use of digitizing the city basic map amended with surveys of details.

The drawing design was binding.

WPG SA utilised the available digital documentation for inspection of data created on documentation sketches and for data acquisition in cases of complicated designing solutions.

It was noticed that data required for laying out some elements on the ground were missing.

- The Świętokrzyski Bridge in Warsaw – construction of the pylon (year of construction 1999). The analogue design was binding – the digital design did not exist.

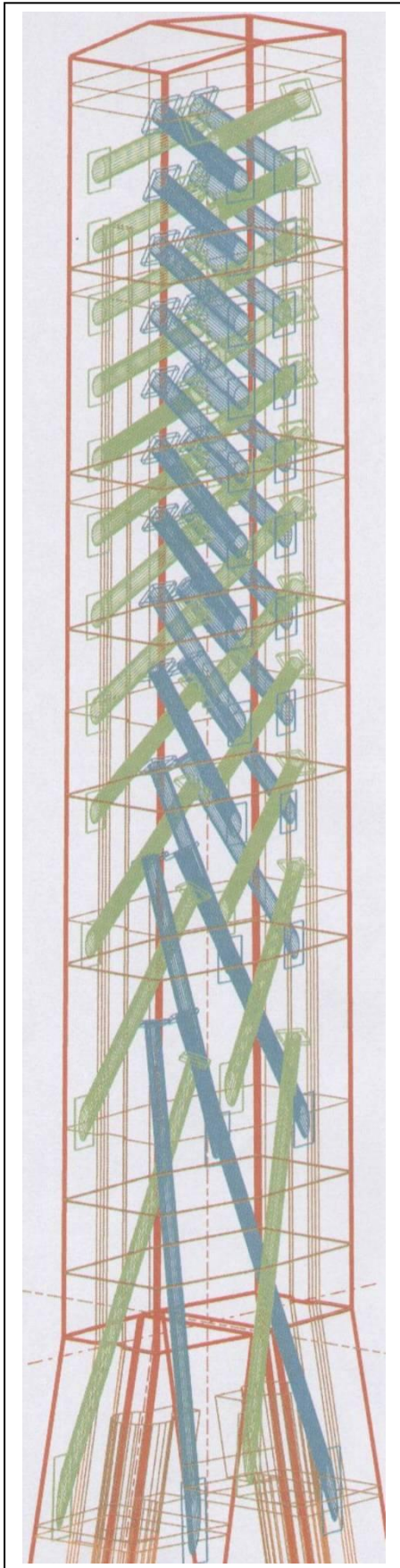
Basing on existing drawings, the WPG SA generated the 3D model of the pylon construction (Fig. 1).

This 3D model was an auxiliary control element in the process of data acquisition for setting out the pylon geometry and location of boarding. Besides, it ensured the possibility to perform checking after inventory of successive fragments of ferro-concrete constructions.

The designing laboratory of the Warbud SA, also developed an independent 3D model; therefore it verified the model developed by the WPG SA.

That moment was a turning point In the approved procedure of co-operation between those two companies; it also allowed to gain experiences which resulted in direction of standardisation of the WPG SA co-operation with building

companies in the field of development of surveying documentation for the needs of surveying services for building sites.



- “The Golden Terraces” in Warsaw (years of construction 2003-2007) were the most representative site, where circulation of the designing documentation forced untypical operations in the field of co-operation between the designer and the surveyor, due to untypical logistics of successive phases of construction. The digital map developed by the WPG SA for designing purposes, as well as binding designing documentation, existing in the digital form – while drawing documentation almost did not exist – forced the utilisation of IT technology at almost all stages of construction. Such organization of works at the construction site has guaranteed the surveyor the complete familiarisation with designing assumptions, the appropriate co-operation with the designer and building entities, safety in the field of professional responsibility (the surveyor checked the design, the contracting unit and the surveyor himself with respect to setting out works), what significantly increased the surveyor’s professional prestige, especially with respect to setting out untypical geometric structures, i.e. supporting structure elements, which were skewed, rotated in various planes and based on connecting curves.

Fig. 1. The Świętokrzyski Bridge – the 3D model of ferroconcrete construction of the pylon and the sleeves for fastening the carrying ropes.

ORGANISATION OF DESIGNING DATA FLOW IN THE PROCESS OF IMPLEMENTATION

Depending on the assumed form of the above discussed designing documentation, the data flow process may have various forms.

The following forms may occur:

- In the case of the drawing form of the designing documentation with the clause „to be implemented”.

For example:

- designing modifications are usually presented in the course of successive revisions, where the drawing number is marked in an appropriate way,
 - in the case of fast changes, data may be transferred in the form of faxes with the designer’s signature, or in the form of e-mails. This process should be carefully performed; it may generate mistakes resulting in unexpected consequences.
- In the case of the digital form, this process is slightly different and sometimes it may be disputable; however formally it maintains and guarantees the system and substantial correctness.



Fig. 2. The Golden Terraces – the general view in the process of construction.

For example:

- the designing documentation of the „Golden Terraces” site was developed following the continuing implementation works (Fig. 2). It was successively transferred on CD-ROMs and it covered successive floors of particular structures.

Each CD-ROM was marked by the design distribution section (Skanska Company) and it was issued to surveyors after confirmation in writing.

- designing modifications were presented and documented in a similar way.

In the process of implementation of the “Golden Terraces” site the number of partial designs has reached the level of about 6000, what proves the complexity of the documentation circulation. In the case of such number of designs, computer searching was the only method, which enabled the WPG SA surveyors to utilise appropriate and the most reliable versions of designs.

THE SYSTEM OF DESIGN CONTROL (ANALYSIS)

It turns out from many years of experiences, as well as from the assumed method of the surveyor’s work at the construction site, that the process of inspection performed for all stages of implementation is a very important issue; if it is not observed, it may result in unexpected and unpredictable consequences. This refers to inspection of the design itself and geometric elements defined by the design, performed by surveyors, as well as the process of services performed by the surveyor at the construction site.

With respect to the basic aspects it refers to:

A. Checking the correctness of modular network axes:

- For example, in the process of implementation of aluminium facades at the “Golden Terraces” site, the WPG has detected many variations in modules of the axis network (mistakes equal to 2 cm). They were probably created in the process of copying of module elements and then, during the stage of development of own 3D models of tilted facades, which was performed by companies hired to carry out those tasks.

B. Checking dimensioning chains in designs.

- Such errors were many times detected in designing drawings.

C. Checking the geometry of repeatable elements.

- In the case of construction with continuously changing geometry repeatable elements should be checked at successive levels. In the case of the “Golden Terraces” this referred to communication shafts only. This ensured the correctness of the entire drawing.

D. Development of own 3D models of implemented structures basing on designing drawings and tables including the description of location of given elements or objects.

- For example, in the case of implementation of the Świętokrzyski Bridge, in order to control the tilt of the sleeve which fastens the rope in the pylon, the 3D model was developed as a result of performed analysis, which presented the connection of the pylon with the bridge plate (a part of the bridge plate was not the subject matter of implementation performed by the WPG SA). As a result of that operation, the full control of correctness was achieved of data used for implementation of the 75 meters high pylon, including rope fastening sleeves, assembled in its body (Fig. 3, 4).



**Fig. 3. The Świętokrzyski Bridge
- platforms on the pylon serving for
assembly of the bridge carrying ropes.**



**Fig. 4. The Świętokrzyski Bridge
- the pylon with rope fastening sleeves.**

SYSTEMS OF CONTROL OF SETTING OUT AND PLACING BOARDING ELEMENTS

- **With respect to setting out this usually consists of:**
 - **carrying out of checking surveys of points or elements of construction, which have been independently set out. In the case of the pylon, this process consists of checking surveys of the distance between two tilted pillars at the specified altitude.**
 - **registration of set out point at the electronic station, and export of acquired data in the form of co-ordinates to the recently updated designing drawing, recorded in the digital form (the highest letter of revision).**
This method allowed to detect erroneous setting out of an arc-shaped edge of one of the floors at the „Golden Terraces” site. This was caused by the fact that the documentation drawings were developed too early and they preceded the new revision, which had not been noticed.
- **With respect to the process of placing the boarding:**
 - **control of the boarding of complicated shapes, as well as set out constructional fragments basing on 3D models.**
For example, in the course of construction of successive sections of the pylon of the Świętokrzyski Bridge, boardings were controlled according to specified cycles, by means of export of data recorded in the electronic station TCA 2003, to the 3D model; this allowed to ensure whether the given section of the pylon was located in an appropriate place and, whether the assumed tilt, was achieved.
In the process of implementation of the “Golden Terraces” serious difficulties were caused by geometry of tilted pillars, which were designed in arcs. Axes of pillars were the only data which were available for the WPG SA. As it turned out as a result of analysis of those data, those axes were defined as cross sections of a cone with the surface of a sphere of given parameters.

In the course of setting out works, performed basing on those data, the WPG SA has generated – using the AutoCAD software – the appropriate spatial curve for the design and the final spatial model of the pillar was developed basing on location of the pillar foundations and its dimensions. This model was the basis for setting out and for control of placing of the boarding. It may be noticed that the company which was to make the boarding had serious difficulties with it and finally, the boarding was not made correctly. Detected deviations from the designed values reached even $\pm 5\text{cm}$. In order no to delay implementation of works, the constructors considered those deviations as permissible.

THE SURVEYOR'S RESPONSIBILITY PATH IN THE PROCESS OF DEVELOPMENT OF SHAPES OF IMPLEMENTED OBJECTS

Experiences gained as a result of implementation of discussed works allowed for formulation of several opinions, which are important from the point of view of surveying operations.

It may be stated that:

- **There is an absolute demand for controlling the most updated designs:**
 - it should be required that the department of the general contractor, which is responsible for distribution of designs is responsible for submission of binding designs to the surveyor (or to surveying services at the construction site) as soon as possible; those designed should be delivered in the form of drawings or in the digital form, dated, signed and equipped with appropriate clauses,
 - the surveying services should be obliged to develop a documentation setting system at the construction site:
 - a. Particular files should contain drawings, in sequences corresponding to adopted revisions. Outdated designs should be described by the clause, which specifies periods of their validity.
 - b. It is recommended to introduce CD-ROMs setting with a Read-Only clause and to prepare textual descriptions of their content.

When a successive CD-ROM is received it should be immediately copied into an appropriate computer folder. If this operation is not performed, this may result in utilisation of outdated designing documentation.

For example: In the course of implementation of the floor construction at the “Golden Terraces” site, incorrect location of a beam was discovered. After checking its location and after exporting data to AutoCAD, to the recent design revision, the correct location of that beam was stated. After investigation performed by the General Contractor it turned out that the WPG SA had not received the latest design – the documentation transfer system failed. Fortunately, not on the surveying side.
 - c. The system of informing the construction site management on designing discrepancies discovered basing on analysis of various designs concerning the same elements, should be formalised.
 - d. A documented system of consultancy with the designing office. concerning all discrepancies, which have been noticed in the design should be established.

THE ISSUE OF THE SURVEYOR'S ACCESS TO DESIGN DOCUMENTATION IN THE PROCESS OF IMPLEMENTATION OF CONSTRUCTIONS

It may be generally stated that:

- a. In the case of implementation when drawing documentation is applied in the analogue form, this may be a very serious issue since sometimes only a part of that documentation is available for surveyors. This results in disturbances in the course of analysis of the design, since some detail drawings have the „higher importance” clause in relation to general ones – this, for example, refers to drawings of concrete reinforcement, girders, walls or pillars. This requires particular attention and focus to be paid by surveyors before any implementation works are commenced.**
- b. In the case when the design documentation is maintained in the digital forms, the situation is correct. Then, the surveyors have the complete documentation and they can analyse it before any implementation works are commenced. As it was mentioned, this happened at the „Golden Terraces” site, when the WPG SA had the access to about six thousand designing drawings in the digital form; this allowed for the complete analysis of all selected elements of construction. After that analysis surveyors might state that some drawings of the same elements (for example elements of construction, concrete reinforcement or boarding) contained certain discrepancies. Fortunately, after communicating those cases, disputable issues might be updated by designing services, what allowed to avoid many conflicts.**

ISSUE RELATED TO SOFTWARE AND DATA FORMAT EXCHANGE BETWEEN DESIGNING AND IMPLEMENTATION WORKS

The issue of introduction of IT solutions into the designing process has some natural implications in the system of surveying services and it is connected with existing and used software tools.

Usually, AutoCAD in its successive versions, is used for designing purposes in the building sector. In the past this was in conflict with Bentley MicroStation software, as well as with other software used by surveyors; it also caused some problems with data exchange formats. At present, due to format unification and possibilities of universal utilisation of various data formats (as DXF format, for example), this issue is not important; however it is the subject of some discussions concerning the possibility of full conversion of some data (for example referring to letter types etc.).

Experiences of the WPG SA prove that the following rules should be met in practice:

- a. To apply identical or compatible (with respect to data formats) software which is used by the designing office,**
- b. To operate, if possible, in the data flow system used by the General Contractor (see the Golden Terraces, services performed for the “UNO Traffic Circle”)**

CONCLUSION

What will be future evolution of methodology of data preparation for setting out and post-implementation control of investments? Such a question should be answered soon.

It should be expected that the started process of development between the designer and the surveyor will only modify this process and result in its full compatibility, to say in using the IT language.

This is the only key to the full implementation synergy, which ensures correct implementation of every investment, both, in the phase of design and implementation – this correctness of implementation is the surveyor’s care, since the surveyor transfers each vision of architects and designers into the reality.

The WPG SA has numerous experiences in this area – we are very glad that those experiences have been already noticed by large building companies.

If would be very useful to make them technical and technological standards and to achieve their reflections in the building and surveying laws, as well as implementation and arbitrary references in technical instructions for both sectors.

Professional consultancy – Jacek Uchański

Scientific consultancy – Witold Prószyński