PROCESS OPTIMISATION FOR THE REHABILITATION AND STRENGTHENING WITH TEXTILE- REINFORCED CONCRETE

R. Schach, M. Hentschel, Institute of Construction Management, Technische Universität Dresden, Germany

ABSTRACT: Based on a transfer project in the special research field 528 of the DFG[1], the process-technological foundation was laid to apply textile reinforced concrete in order to strengthen building elements. In this case, criteria were defined which generally must be evaluated in introducing a new construction process. Generally speaking, construction projects can be implemented on the basis of different methods of construction. Typical construction-related assessments can usually be classified into different categories focusing on costs, required construction time, quality of the work, influences on the environment or in respect to safety and health aspects. [SCH01]. The current paper describes the procedures involved to determine significant values[2]. It presents the precise manner in which it is possible to use experience and typical methods derived from other areas of science to develop these values.

1 INTRODUCTION

The introduction of new construction processes in companies fundamentally follows a previous research and development (R&D) phase. Within the framework of this R&D phase, relevant tests are initially carried out in respect to the materials being used. In order to minimize risks at an early stage in the new construction process, it is also essential to demonstrate that the targeted specifications of the process are feasible, realizable and realistic when put into practice at a later date. Experience shows that before the introduction of new construction processes, companies usually do not have comparative values at their disposal derived from tried and tested, field-proven applications. In order to determine specific properties of the materials and processes in use, experiments can generally be carried out on small-sized elements in laboratories under constant and controlled laboratory conditions. However, it is much more difficult in a laboratory environment to study building components featuring the dimensions used at typical construction sites, and to generate the varying environmental conditions which can be expected in practice. For this reason, the Technical University of Dresden (TU Dresden), more specifically the Institute of Construction Management, has been accompanying the above-mentioned transfer projects within the framework of the DFG special research field 528[3]. The focal point of the project is, amongst other objectives, to enable large-scale testing[4] on specially produced pre-fabricated sections. In this way, typical applications are systematically simulated and evaluated complementary to pilot projects on strengthening materials us-

[1] German Research Foundation (Deutsche Forschungsgemeinschaft - DFG): www.dfg.de
[2] For examples: performance factors and cost values
[3] Project name: „Bemessungsmodell und Applikation für Biegeverstärkung von Stahlbetonplatten”
[4] Large-scale test represents a test, that is realized on a test site with frameworks and unit dimensions, that are typical for praxis sites.

ing textile-reinforced concrete, that had been realized in last year's without a systematic data collections. [SCH01], [SCH02] The implementation of these large-scale testing are designed to provide important information and conclusions about how the designated criteria relating to construction time, quality, costs, environmental influences and occupational safety can be linked to one another. The aim is to develop values which are specially tailored to these new construction processes, which in equal measure describe the costs, benefit, comparability and optimally process and work sequences as well as the underlying conditions, and which can be subsequently drawn upon as the basis for the risk assessment.

Generally, any testing of new construction processes are based on practical considerations on how to optimally prepare and narrow down the scope of the individual process steps, for example in the implementation of testing. In this particular case, a method needs to be identified to enable the consistent and uninterrupted evaluation of the process steps for the applied construction method. In addition, a sense of perspective must be maintained i.e. ensuring an appropriate time, effort and cost in determining the new values so that the available resources or financing is not exceeded.

The current paper describes the procedures involved to determine significant values[5]. It presents the precise manner in which it is possible to use experience and typical methods derived from other areas of science to develop these values. Basically speaking, experience from other areas has shown that data collection efforts must be distinguished according to the objectives of the particular analysis. Traditionally, comprehensive data collection is applied for example in the areas of meterology, social research and traffic research [HÖM03].

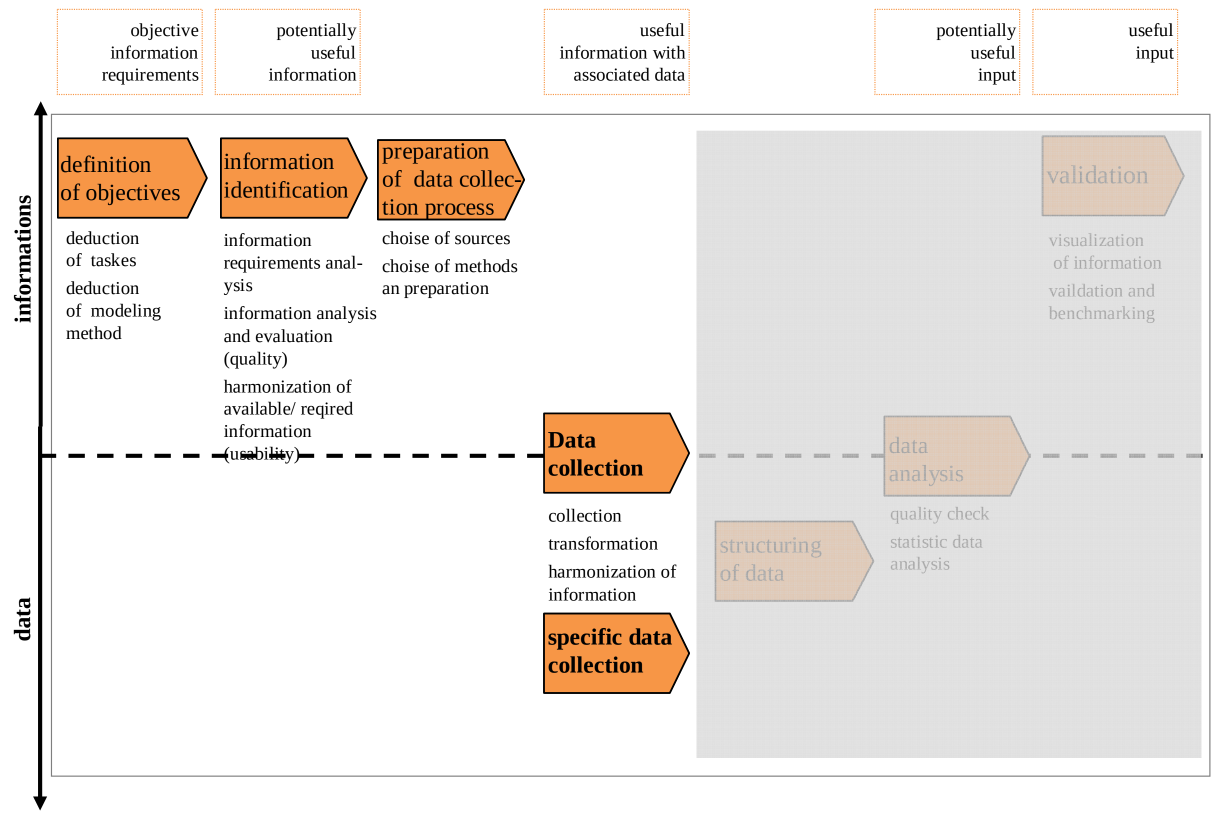

Fig.1.1. Phases of data collection [HÖM03].

[5] For examples: performance factors and cost values

For example, Fig. 1.1. shows which individual phases must be passed through until sufficient data has been gathered. The shaded phase in this diagram relate to the structuring and analysis of the data, which will not be dealt with in this paper.

In this paper, this methodology will be adapted and specified. The individual types and variations in the data collection process and their relevance to the determination of values will be explained. In another section, the various theoretical aspects will be dealt with on the basis of selected sample data which were collected in the large-scale testing of application processes using textile-reinforced concrete.

2 Basics of Data Collection

Fig. 1.1. shows that the definition phase outlining objectives must proceed information identification and the preparation of the actual data collection, also termed data acquisition. This approach is modified in Fig. 2.1. to enable the integration of the special requirements of this particular project.

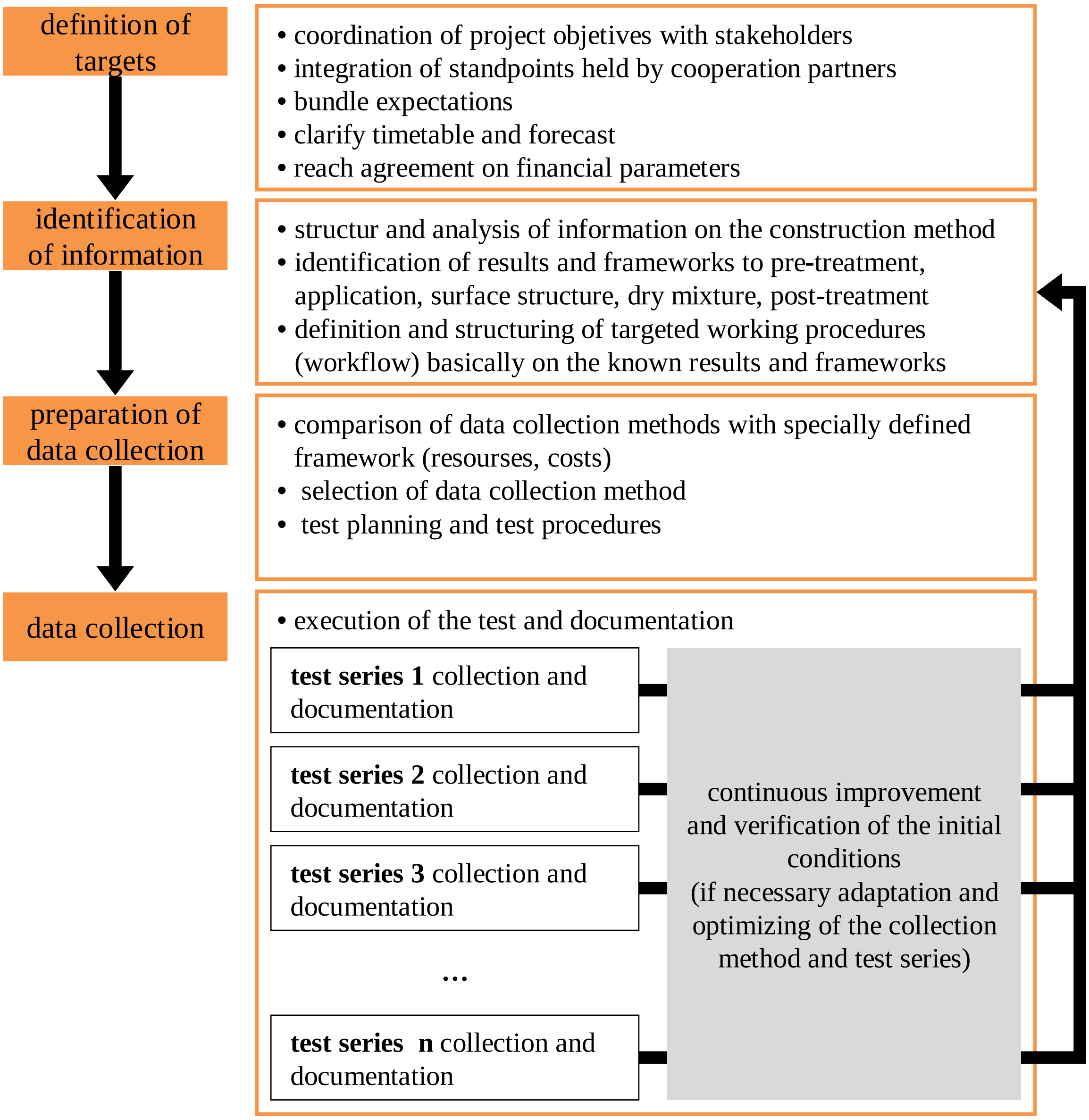

Fig.2.1. Specific phases ending with the data collection in construction methods

The structure of the data collection phase is designed that it is possible to run it arbitrarily often. For this reason, the implementation of large-scale testings were divided into individual test series. The underlying advantage is, that different frameworks can be studied in each test series. In addition, the previous implementation will be discussed between each series of experiments, and therefore the target procedures for each separate trial are regularly checked. This also guarantees that varying conditions and unforeseen influences were immediately taken into account and can be incorporated into an optimized approach for the upcoming test series. This continuous improvement process requires a continually updated data collection.

2.1 Classification of the data collection

The observed data collection in this paper refers only to so-called primary data research. In this method, data will be collected especially for a defined intention[6] [HÖM03]. Basically, in order to collect primary data, one can choose between two models, namely the “interview” or the “observation” model. In the case of the latter method, one differentiates between self-observation and external observation. A third observation form is considered to be valid in respect to stationary industry, namely automatic observation. For example, it is used by counting the single rotation in the assembly-line manufacturing an accurate record of events relating to the period. [HÖM03].

The above-mentioned self-observation is a person-related model and is performed by the person himself whose work processes are being examined. The pre-requisite is that the observed person can carry out this documentation without significantly greater work and expense and without disrupting the actual work processes. Self-observation is in contrast to external observation. Here it is assumed that all data to be collected will be registered by an external observer. There are two principal methods of actual data collection [HÖM03], [KÜN04], [BER05]:

- Discrete time and elapsed time monitoring
- Multi-moment method or the systematic multi-moment method.

2.2 Time monitoring with the discrete time and elapsed time methods

Generally, the schedule time in a construction process exists of different parts (Fig. 2.2.).

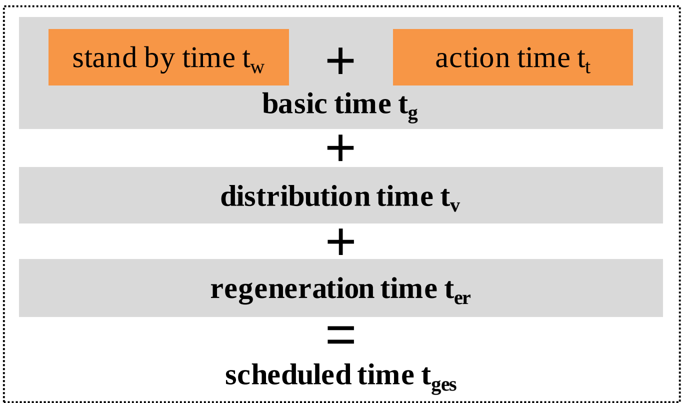

Fig.2.2. Structure of time. [BER05].

[6] The secondary data research means that data collection function on basis other collected datas within the company that are used in another approach (inventory method, document analysis, comparisons, etc.). [HÖM03]. This method will not be treated here in greater depth.

In order to facilitate the introduction of new construction processes in the construction industry, a method should be chosen which is as simple as possible, in order to be able to optimally capture the diverse and changing activities during the monitoring. This applies both to the discrete time and elapsed time monitoring, where a worker is continuously being observed and his activities are being "recorded". A distinction is made between the various activities of the worker. Each individual involved in a construction method is observed separately. Normal watches, stopwatches or DV-based evaluation equipment can be used to facilitate the observation process. [KÜN04], [BER05].

2.3 Time monitoring based on the systematic multi-moment method

The "multi-moment method" process developed by the "Reichsausschuss für Arbeitszeitermittlung", short REFA (now: REFA - Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung – Association for Work Design/Work Structure, Industrial Organization and Corporate Development)[7], founded in 1924, encompasses several random sampling evaluation methods, which lead through statistical analysis of time data. The systematic multi-moment-method is a special form because the sampling does not occur with random intervals (multi-moment method), but at the same observation intervals. In this method every sub-activity that is performed by a single employee will be collected in 3-minute intervals. The advantage is that ensuring equally long intervals enables more precise conclusions to be made about the actual duration. [KÜN04], [BER05].

2.4 Application of modern documentation methods

A key disadvantage of the time observation methods described in sections 2.2. and 2.3 is that it is extremely time-consuming. Moreover, an external person is required for the entire implementation of the various steps in the process and for each person to be observed. In addition, the process described in Fig. 2.1. entailing several test series requires repeated data collection. Conditions can be somewhat optimized by using modern documentation techniques. For example, the individual experiments can be fully documented by video recording. Several video recording devices can be set up at special pre-defined camera sites (fixed location for the camera and tripod), which are coordinated with the local construction site. At least one device is used to ensure the uninterrupted recording of all the process steps in the test series of the construction process. All workers are monitored at the same time. Another camera is used to provide detailed pictures of the construction process. This approach is supplemented by photo documentation and hand-made protocols by the investigator containing all key data. The advantage of this approach is that it is relatively convenient and easy to closely examine and evaluate the authentic documentation on a computer workstation without being pressed for time. Accordingly, the documentation is complete and is open to scrutiny at any time.

[7] Source: www.refa.de

3 DATA COLLECTION USING THE EXAMPLE OF TEXTILE-REINFORCED CONCRETE

The start-up of the project demonstrated that the procedural conditions were much more amenable to the practical building application of textile-reinforced concrete for the strengthening of components than originally expected. Amongst other aspects, this refers to the

• manufacturing of fine concrete,
• equipment to be used for mixing and spraying of fine concrete,
• special features of the application of different textile surface structures,
• and the post-treatment.

These special conditions were recorded and evaluated in the target definition and information identification phases (see the approach in Fig. 2.1.). The project participants agreed on the approach which was previously described to carry out a large-scale trial in several test series in order to selectively enable interim results to be integrated in the further implementation of the testing.

3.1 Working processes and classification of the test series

Amongst other aspects, the essence of a transfer project is founded as the collaboration of two interest groups science and construction practice. The data collected, serving as the basis for the project launch, should be studied in greater depth in cooperation between these interest groups. In turn, this will enable its successful integration into actual construction practice. All participants defined common objectives, which essentially provided a framework and narrowed down the expectations of the project participants. At that beginning of the project one could only refer to laboratory tests which had only been carried out on small-sized building components. In addition to prevous research findings, more detailed conclusions concerning the application of textile-reinforced concrete on larger areas were derived from the renovation of a hypar shell at the Academy of Applied Sciences in Schweinfurt [CUR06], the construction of a bridge in Oschatz [CUR07] and the renovation of a dome and a vault of the tax and revenue office in Zwickau [SCH09]. However, from a construction point of view, questions remain to be answered in respect to the commercial applicability and economic feasibility of this method within the context of a potential nation-wide rollout.

In addition to the planned large-scale experiments and their detailed analysis, a series of preliminary considerations and preparations were necessary in order to answer these unresolved issues. Any of this will be discussed below. For example, within the framework of the test preparations, potential sites[8] for the large-scale tests were examined, and the respective advantages and disadvantages were addressed. Moreover, questions had to be answered about the design of the tests, and available information in respect to the application processes had to be compiled. In this regard, it could be expected that the setting up of large-scale testing stations at the trial site would require a period of several months, in order to be able to flexibly react to external influences (i.e. weather conditions). Furthermore, it was essential to enable a series of tests to be performed within a short time. As described above, there had only been sporadic pilot projects which were only of limited comparability to the desired test series.

On the basis of the information compiled from previous applications and the experience of individual project participants, a targeted workflow of a test series was develop, which also

[8] sites closed to research laboratories and sites in prefabricated unit companies

outlined the main activities to be carried out. Part of the targeted workflow is outlined in Fig. 3.1, including the assignment of people to each of the individual main-activity. The precise responsibilities are added at a later point in time.

target – construction method workflow	
main activity	**person**
test series 5	
installation of the mixing machine	person 1
installation of the injection machine and hoses	person 2
preparation of the mixing machine site	person 1
preparation of temporary storage area for water and sacks	person 1
preparation of the concrete surface for the reinforcing work	person 3
preparation of safety and health infrastructure	person 4
assuring provision of resources at the mixing machine	person 5
injection of the concrete	person 2
application of the textile	person 3, 4
monitoring of the work	person 6
…	…

Fig. 3.1 – Part of the Target – process of the construction method of one test serial

On the basis of the targeted workflow, it was essential to clarify which technical equipment, resources and tools were necessary for implementing the respective test series. In addition, it also had to be decided how the detailed data acquisition could be carried out under these conditions. It was decided that two video cameras should be used. Therefore, camera 1 would be installed at a fixed position in order to deliver a constant perspective across the test series. This approach ensured that the data collection for all individuals could be ensured by using only one camera. Camera 2 would be used for variable data acquisition.

3.2 Strengthening with textile-reinforced concrete on a wall

The following section presents some of the steps required for the production of textile-reinforced concrete by using carbon textile and fine concrete in large-scale test runs. First, the rolls of carbon textile are delivered directly to the test site and are accurately cut directly on site into textile scrim webs. [SCH02]. The size and the required quantity of these textile scrim webs were determined on location. As a rule, three layers are planned. The following marginal conditions could vary:

- the direction of the textile scrim webs, considering the different load bearing properties of the rovings,
- overlapping of the textile scrim webs,
- number of layers,

- installation situation (vertically on the wall, horizontally on the ground, horizontal overhead),
- number of workers deployed in the application team.

Fig. 3.2. shows how the vertical surface is first sprayed with a layer of fine concrete, using by the spraying operations manager. The thickness here ranges from 3 to 6 mm, depending on the finish of the surface. Subsequently, the laying team (usually consisting of 2 to 3 people) lays the textile scrim webs in the pre-defined direction. The textiles are impressed onto the concrete with ordinary trowels. This is easily accomplished by applying slight pressure (Fig. 3.3.) when the right mixture of fine concrete is achieved. Finally, each track must be inserted completely onto the fine concrete in order to be wetted by it. (Fig. 3.4.). On balance, it adds up to a thickness of about 10 to 12 mm, if there will be laid in three textile scrim webs.

Fig. 3.2. Injection of the wall by person 2

Fig.3.3. Application of textile by persons 3, 4, 5

Fig. 3.4. Smoothening by person 3

3.3 Data collection with a sample person

As described in section 3.1, the acquisition of data occurs in conjunction with two video cameras. Fig. 3.5. shows the general scheme of the testing setup. This includes an outline of the testing ground. After the set-up of all testing facilities, a scaled plan of the site was created showing the complete test site. This offers the possibility to determine the recorded times in relation to the distances covered at the test site.

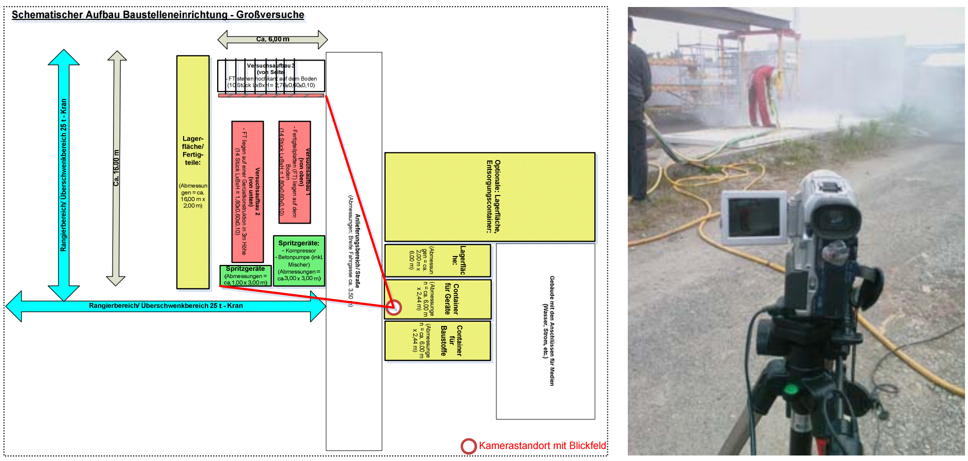

Fig. 3.5. Scheme of the test site with camera stand location

The discrete time and elapsed time methods were used to collect data. As described in section 2.2, the essence of this method consists in the fact, that each person and each activity is recorded, in order to create a consolidated balance sheet per person. Using the example of one person (injection manager), Fig.3.6. shows how a data sheet looks like.

time recording – person 2							
sub-activity	switch on compressor	Start injection of concrete - 1st length	Break	help for person 3	Continuous injection concrete 1st length	break	Sampling for „Hägermann Test“
Time code camera 1 [h:min:s]	00:47:44	00:48:29	00:50:24	00:51:32	00:53:49	00:55:33	00:55:51
discrete time recording [min:s]		00:45	01:55	01:08	02:17	01:44	00:18
elapsed time recording [h:min:s]	09:56:15	09:57:00	09:58:55	09:59:03	10:01:20	10:03:04	10:03:22

Fig. 3.6. Data sheet for data collection

4 FORECAST IN DATA ANALYSIS AS BASIS FOR DETERMINBATION OF VALUES

The data collection procedure described as above and the trial runs which were already carried out test series produced a considerable amount of documentation on the activities. For example, more than 40 full hours of film footage are ready for evaluation. These are now being evaluated and analyzed in detail in the subsequent project phases. Only after this step has been completed is it possible to draw conclusions about the working parameters which are relevant to this construction method. The determined values are compared to the known conditions and evaluated by means of different evaluation methods[9]. This analysis enables the quantification and classification of significant construction parameters in respect to the benefits and comparability to other construction methods.

ACKKNOWLEDGEMENT

The authors thank the following companies, which supported the project as cooperation partners:

- Bilfinger Berger AG makes available, amongst other assistance, specialized technical staff and equipment.
- Putzmeister AG provides the necessary application technology and know-how on the mixing, spraying and application of the fresh concrete.
- Pagel Spezialbetone GmbH & Co. KG (PAGEL), specializing in special concrete, is providing considerable support in the development and delivery of a suitable dry concrete mixture.

[9] For example: cost-benefit-analysis, cost-effectiveness-analysis, utility analysis. [SCH08].

The Institute of Construction Management and the Institute of Concrete Structure at the Technical University of Dresden, both part of the Faculty of Civil Engineering, are in charge of the project. The inter-disciplinary collaboration with other project participants conducting special research is a generally accepted practice. In particular, it is important to mention the cooperation with the Institute for Construction Materials of the Faculty of Civil Engineering and the Otto-Mohr-Laboratory (OML), which is also part of the faculty.

REFERENCES

[SCH01] Schach, R.; Hentschel, M.; Grundlagen für die Nutzwertanalyse für Verstärkungen aus textilbewerten Beton.; Textilbeton – In: Curbach, M.; Jesse, F. (Hrsg.); Theorie und Praxis, 1. Auflage, Dresden, 2009,

[SCH02] Schach, R.; Hentschel, M.; Verfahrenstechnische Grundlagen für die Verstärkung mit textilbewehrten Beton im Hochbau.; In: Motzko, Christoph (Hrsg.): Baubetriebliche Aufgaben. Festschrift anlässlich des 30-jährigen Bestehens des Instituts für Baubetrieb der Technischen Universität Darmstadt; Düsseldorf: VDI-Verlag (Fortschrittberichte VDI /4, 211) 2009

[HÖM03] Hömberg, K.; Jodin, D.; Leppin, M.; Methoden der Informations- und Datenerhebung; Technical Report 04002, **ISSN 1612-1376**, Universität Dortmund, Lehrstuhl für Förder- und Lagerwesen, 2004

[KÜN04] Künster, G.; REFA in der Baupraxis, Teil 2 Datenermittlung, REFA Verband für Arbeitsstudien und Betriebsorganisation e.V., Darmstadt – Fachausschuss Bauwesen – im Einvernehmen mit dem Hauptverband der Deutschen Bauindustrie e. V., Wiesbaden/ Bonn, dem Zentralverband des Deutschen Baugewerbes e. V., Bonn, und der Industriegewerkschaft Bau-Steine-Erden, Frankfurt am Main (Hrsg.), ZTV-Verlag, Neu-Isenburg, 2. Auflage, 1991

[BER05] Berner, F., Kochendörfer, B., Schach, R., Grundlagen der Baubetriebslehre, Teil 3, Baubetriebsführung, Vieweg+Teubner, GWT Fachverlage GmbH, Wiesbaden 2009, 1. Auflage, 2009

[CUR06] Curbach, M.; Hauptenbuchner, B., Ortlepp, R.; Weiland, S.: Textilbewehrter Beton zur Verstärkung eines Hyparschalentragwerks in Schweinfurt. Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Beton- und Stahlbetonbau 102 (2007), Heft 6, 2007.

[CUR07] Curbach, M.; Graf, W.; Jesse, D., Sickert, J.-U.; Weiland, S.: Segmentbrücke aus textilbewehrtem Beton. Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Beton- und Stahlbetonbau 102 (2007), Heft 6, 2007.

[SCH08] Schach, R.: Investitionskosten der Verkehrswege Transrapid und ICE. Tagungsband zur 1. Dresdner Fachtagung Transrapid, Dresden, 2001

[SCH09] Schladitz, F.; Lorenz, E.; Jesse, F.; Curbach M.: Verstärkung einer denkmalgeschützten Tonnenschale mit Textilbeton. Beton- und Stahlbetonbau 104 (2009) 7, S. 432-437 – doi:10.1002/best.200908241