Quality Evaluation of Construction Activities for Project Control

Marco A. Bragadin[1], Kalle Kahkonen[2]

[1]Departement of Architecture, Alma Mater Studiorum University of Bologna,
Viale Risorgimento, 2 – 40136 Bologna, Italy

[2]Department of Civil Engineering, Tampere University of Technology,
Tekniikankatu, 12 – 33720 Tampere, Finland

[1]marcoalvise.bragadin@unibo.it; [2]kalle.e.kahkonen@tut.fi

***Abstract*-The measurement of the performance of a construction project is a fundamental task of Construction Management. This is usually based on professional observations or use of metrics such as Key Performance Indicators (KPIs), that are intended to represent the health of the construction project and can be used to predict the future project performance.**

This paper presents a research effort on the way forward to implement quality related metrics for construction project control. The Quality Breakdown Structure is adopted as basic tool to consider the various elements of construction quality like product quality and process quality, to put them into relationship and to evaluate their relative weight in the construction project and its sub-processes.

The proposed quality related performance indicators can be loaded to the construction project scheduling model, with the goal of showing to Project Manager and to Stakeholders the achieved versus planned quality in the project status. This could improve construction project control process, with the aim of the timely implementation of corrective actions to achieve project success.

Keywords- Construction; Project Control; Quality; Project Managemen; Construction Performance

I. INTRODUCTION: PROJECT MANAGEMENT METRICS AND KPIS IN CONSTRUCTION

Nowadays the construction project management needs much more meaningful information than in the past. In fact several driving forces have improved the need for information in construction projects:

- construction projects we are working now are made of more sub-processes than in the past, thus improving project complexity;
- construction project total duration is always increasing;
- economical and financial efforts for stakeholders are increasing;
- as technology increases its complexity, time and cost requirements are becoming more and more difficult to satisfy;
- complex construction projects need well organised management with detailed and up to date information.

All of these driving forces and the market performance problems make the need for meaningful information of capital importance to achieve project success [1]. In fact project success can be achieved only with the support of an integrated Project Reporting System, based upon a specific Project Measurement System that has the task of monitoring project performance with a metric system to allow Project Managers to implement timely and proper management actions to meet project objectives, milestones and deliverables. So project metrics should be reported in a timely manner (with the goal of having real time data), should be oriented at the adherence of the competing constraints (i.e. time, cost, quality, etc.) and must be used to implement corrective actions to maintain baselines. Project metrics can include: time, cost, scope, quality, customer satisfaction with project performance, safety, risk mitigation and many others like: continuous improvement; benchmarking; accuracy of the estimates; accuracy of the measurements; accuracy of the targets for the metrics. In addition to this Project management process metrics have to be directly related to lessons learned and best practices, and is directed to stakeholders, working levels and management [2].

The measurement problem in construction projects is a well-known project management issue. Metrics in project management are a measurement of project performance, but not all metrics are equal in importance. Reference [2] divides project measurement into “normal” metrics and Key Performance Indicators (KPIs). Key Performance Indicators are those critical metrics that can define in a concise and proper way the project status and can be used to forecast the future project performance. The KPIs are the information needed by project team and stakeholders for decision making.

Reference [3] defines three categories of metrics:

- Results Indicators (RIs), give information about what has been accomplished;

- Performance Indicators (PIs), give information about what must be done to increase or meet performance requirements;
- Key Performance Indicators (KPIs), the critical performance indicators that can drastically increase performance or accomplishment of the objectives.

In Project Management Practice there are several metrics that can be identified for project measurement, but while decades of metrics can be defined, only few of them can be used as KPIs. In construction project management there are some measures of building products and processes quality that are mandatory by law and some other ones that are requested by owner/customer through contract documents and specifications. Traditionally the performance of construction projects is measured by means of three performance indicators: cost, time and quality. Recent research employed additional performance indicators to better evaluate construction projects. In particular the Minister of Construction of the United Kingdom [4] identified six KPIs: cost, time, quality, health and safety, business performance and change orders. Instead, updated research [5], added to time, cost, quality, and safety KPIs, the following KPIs: environment impact, client and project team satisfaction, and technology transfer.

Reference [2] reported the following KPIs for the case studies of Disneyland and Disney World: time, cost, scope, safety, aesthetic value and quality, with the last three being fixed values that could not be negotiated. Reference [6] for pharmaceutical construction projects included only the following KPIs: cost, time, quality, safety and design/space efficiency. While all of the described KPIs are of greater interest in Construction Management, it is believed that the quality KPIs are the most important ones, and so the present paper focuses on the development of quality KPIs.

II. RESEARCH METHODOLOGY

The aim of the paper is the definition of quality – related KPIs for a construction project for project control purposes. Indeed quality assessment for a construction project is a very difficult task for both Project Managers and Stakeholders due to project complexity, in fact construction involves a lot of different trades and needs many professional specializations. Thus technology oriented quality assessment can be an interesting point of view to limit the boundaries of the problem.

Assuming that for a public housing construction project there are at least more than an hundred types of different activities that have to be related to the dimension of the building, the problem of quality assessment of each activity can be overwhelming. In fact each activity quality is defined by the satisfaction of a number of requirements set by national or local laws and regulations and / or set by the project contract, documents and specifications.

The solution can be searched in activity sampling for tests and in weighting each activity quality to a percentage of the overall project quality to be able to sum up the different types of quality performance.

As Project quality is made of two main parts, product quality and process quality, it is important that both are taken into account for the project quality assessment. Only in this way construction quality assessment will be related to total quality assessment. This quality assessment methodology could be a good estimate of the overall project quality but it is not really building and construction process quality. It is only one of the various Project Performance Indicators to measure project performance.

The study of previous literature about construction quality estimate and construction project metrics has allowed benchmarking and analysing existing approaches to construction project quality evaluation, highlighting positive and negative issues of each approach. The research is also based on two real construction projects that have been described from the quality standing point in recent studies performed at the University of Bologna [7, 8].

The main task of the research is the definition of a method to assess project quality performance through the as – of date for project control purposes. Note that the quality assessment performed with the proposed method is an evaluation of total quality project performance which can be used also for contract purposes, but it is not meant to be a quality certification of the building or construction project.

The research is developed into three phases. In the first phase literature about project metrics and construction projects performance measurement is reviewed. In particular existing and proposed project quality KPIs computation methods are focused.

In the second phase the activity quality performance quantification problem is tackled. First it is needed to specify activities of the construction project through a Quality Breakdown Structure (QBS) that identifies work packages that group activities with similar quality specifications. The Work Packages (WPs) of the QBS are the smaller groups of activities which have the same quality specification. Than the proposed method for quality KPI estimation evaluate the quality performance of Work Packages related to two groups of requirements: product or sub-products related requirements and process or sub – processes related requirements. The selection of the most important requirements between these two groups allows defining WP quality items that compose WP quality and thus allowing quality measurement and aggregation by a weighting system.

This weighting system is the core process of quality KPIs computation. The QBS allows identifying the quality control

points of the construction project (Figs. 1 and 2).

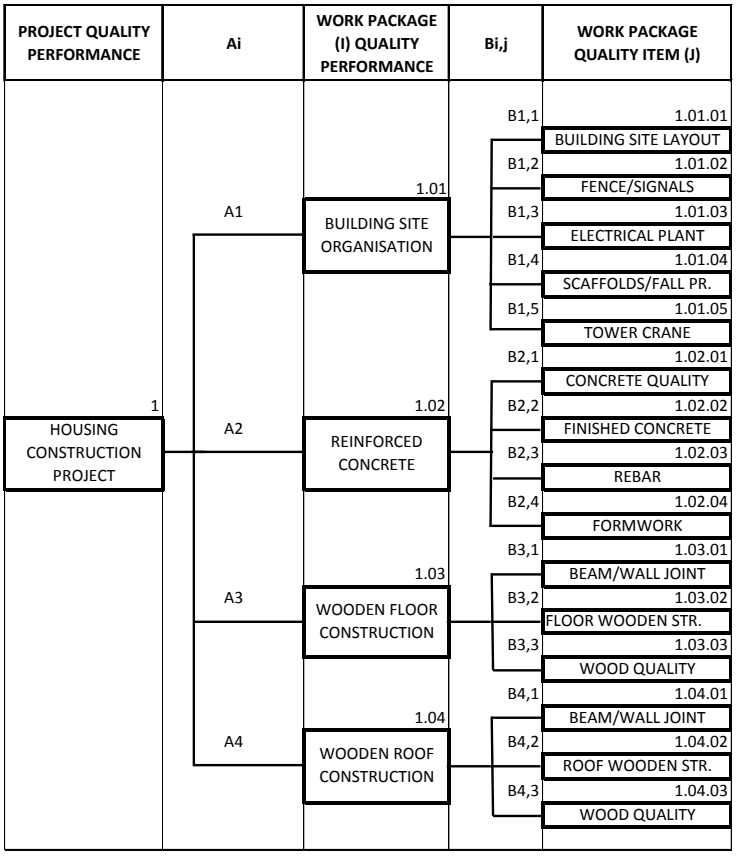

Fig. 1 Sample Quality Breakdown Structure for the example project

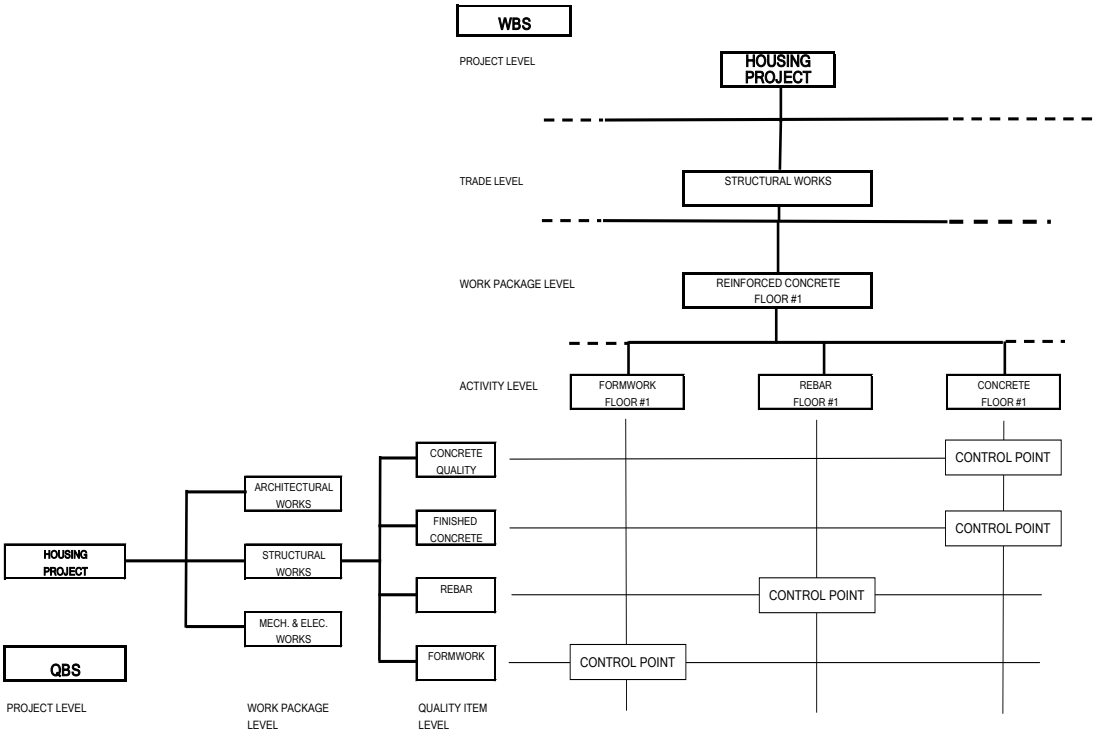

Fig. 2 Matrix relation between QBS and WBS elements

In the third phase overall project quality assessment through the as-of date is performed. This is allowed by quality weighting of the WP of the QBS. The weighting system at the project scale is realised taking into account economic, aesthetic or functional aspects of the specific construction project. Than by adding the weighted WP performance of each WP accomplished at the as-of date, the quality project status can be evaluated at each time-now or on a real time basis.

III. APPROACHES TO QUALITY KPI EVALUATION IN CONSTRUCTION

In construction projects the measure of quality performance is a complex task as, in general, construction project are complex projects [9]. While for time and cost it is easy to define some quantitative indexes to measure time and cost performance and so define easily some relevant KPIs, it is much more difficult to quantify and measure quality performance of a construction project and develop related to quality meaningful KPIs.

Indeed quality is basically technology related and the metrics of quality must be specific for each kind of project. For construction, few are the methods and approaches aiming at an overall project quality assessment that can quantify a quality KPI. This section intends to provide a review of three important approaches to quality KPIs development (Table 1). The three approaches were selected because of their relevance and their presentation in prestigious international scientific journals.

TABLE I DIFFERENT APPROACHES TO CONSTRUCTION PROJECT QUALITY MEASUREMENT

	Project quality KPIs approach	**Criteria**	**Quality Breakdown Structure (QBS)**	**Quality type**	**Quality Metric**
1	The KPIs Working Group [4]	Number of Defects/Quality issues	No (list of Quality Issues)	Product Quality	Score 1 - 10
2	Building and Construction Authority – "conquas" [10]	Quality indicators for standard Work Packages weighted with CONQUAS criteria	Yes, but standardized QBS for each building category	Product Quality	Percenta-ge quality index
3	El-Rayes and Kandil [11] [12].	Quality indicators for each activity with relative percentage weight	Yes, specific for the single project	Product Quality	Percenta-ge quality index
4	Present Paper	Quality indicators for each Work Package with scoring system	Yes, specific for the single project	Product and Process Quality	Percenta-ge quality index

The first approach [4] defines the quality KPIs basically as the frequency of defects in the end product. In fact the KPIs Working Group of the Minister of Construction of the United Kingdom assumes that quality in construction is subjective and means different things to different process operators, and that there is no objective recognised method of measuring quality in construction industry. So the aim of the quality KPIs is to improve the visibility of quality issues on construction projects through the measurement of "Quality Issues". A "Quality Issue" is defined as an issue that affects the project so that work needs to redone, modified or compromised to a lower standard than originally agreed. Therefore the KPIs measure construction quality recording all quality issues on all elements within the project from project commencement. At the operational level the KPI for quality is the number of quality issue, while at the project / headline level the Quality KPI is called Defects KPI and it is recorded using a scoring system with the score 10 for a product/element apparently defect free and a score 1 for a totally defective product. It is worth mentioning that in this approach there is another quality – related index which is Client Satisfaction, divided in four subcategories each with a score from 1 to 10. In fact, from a Total Quality Management standing point Client Satisfaction is an important quality-related element. This approach measures how satisfied is the client with the finished products, and with the service of the contractors using the score against the 1 to 10 scale, with 10 meaning totally satisfied, 5/6 neither satisfied nor dissatisfied and 1 totally dissatisfied. At the operational level the KPI measures how satisfied is the client with certain client - specified criteria, using the score against the 1 to 10 scale, but weighted together to determine their level of importance.

The second approach is the one of the Construction Industry Development Board of Singapore that developed an objective quality measurement System for building construction called CONQUAS, which is now also used as a quality standard for ISO 9000 local enterprises quality certification [10].

The CONQUAS system indicates criteria for measuring construction quality and determines to what extent a project satisfies those requirements, related to a representative sampling of the building. Quality metric is based upon a scoring system that considers Building Quality divided into three primary component areas: Structural works, Architectural works and Mechanical and Electrical works. The weight system is a compromise between the cost proportion of the three components and their aesthetic value, related to the following building categories:

- Category A/B: commercials, industrial, institutions etc. (A: with central cooling system; B: without central cooling system);
- Category B: private housing;
- Category C: public housing;
- Category D: landed housing (bungalows, semidetached houses, terrace houses etc.).

The procedure to find the construction project quality index starts with the computing of the percent passing the inspection points, depending on sample inspections. This value is combined with other elements in the same component (e.g. formwork and rebar in structural works). The component total (e.g. structural) is weighted a second time based on the building category. The sum of the three component scores is used as the final building score, i.e. the quality index.

The third approach to quality index evaluation is the one used by El Rayes and Kandil in recent studies for highway

construction, in order to facilitate the measurement and quantification of construction quality [11, 12]. The approach is a development of the "Quality – Based Performance Rating System" of the American National Cooperative Highway Research Program (NCHRP) for contractors qualification [13, 14].

The method identifies a number of measurable quality indicators for each activity of the construction project. The indicators are derived from performance based models that correlate the long term performance of the end product of each activity to its quality indicators. Quality indicators are also selected with the aim of allowing practical and objective measurement of performance. Then the quality of each activity of the construction project is estimated on quality indicators basis.

A weighted approach is used to aggregate the estimated quality for all the considered activities to provide an overall quality of the project level. For each activity of the Work Breakdown Structure (WBS) two types of weights are identified: the weight (Bij) of each quality indicator of the activity to indicate the relative importance of each indicator to the others being used to measure the quality of the activity and the weight (Ai) of the activity to represent the importance and contribution of the quality of the single activity to the overall quality of the construction project.

$$Q = \sum_{i=1}^{n} Ai \sum_{j=1}^{k} Bi,j \times Qi,j \quad (1)$$

where Q = overall quality of construction project; Ai = weight of quality of activity (i) compared to other activity in the project; Bi,j = weight of quality indicator (j) of activity (i), compared to other indicators in activity (i); Qi,j = performance of quality indicator (j) in activity (i); n = number of activities of the construction project; k = numbers of quality indicators of activity (i).

The model of Equation (1) allows measuring and quantifying the overall quality of the construction project with a practical and empirical approach.

The three different approaches are synthesized in Table 1.

IV. QUALITY EVALUATION OF CONSTRUCTION ACTIVITIES AND PROJECT QUALITY BREAKDOWN STRUCTURE (QBS)

Quality KPI definition for a construction project is developed through a method defined by the integration of the three approaches previously described. The proposed operational procedure is applied to a simple example project of refitting of two buildings of a public institution [7, 8].

Core tool of Project Management is the Work Breakdown Structure (WBS) that is the structure of the project information integration system [15-18]. Work Breakdown Structure is a key element of traditional project control. The Work Breakdown Structure is a deliverable-oriented hierarchical decomposition of the work to be executed into work packages that organizes and defines the total scope of the project [19]. The WBS is meant to provide an integrated framework for time, cost and quality control of working packages, but the WBS approach to project control is not easy to develop successfully. So to ensure efficient quality oriented control processes it is needed a Quality Breakdown Structure (QBS) [12]. The QBS is a hierarchical decomposition of the construction project into Work Packages (WP) that groups the activities which have the same quality requirements and specifications. A sample of the QBS for the example project is presented in Figure 1.

Work Packages are also groups of activities that satisfy the requirement of time/cost/quality integration for control purposes and are the smallest element to be under control. Work Packages often correspond to contract packages or to pay items of a contract. The quality of every single WP of the QBS contributes to the overall quality of the construction project. The Work Package contributing to project quality is quantified through a weighting system that is set for the specific project taking into consideration economic and aesthetic or functional issues. In Figure 1 the weight for activity (i) is Ai.

For Quality control purposes the Work Package quality is evaluated as a weighted sum of the actual value of each quality item of a work package. The weighting process is performed with a scoring system that weights each quality index related to final WP quality. In fact, as a matter of facts, building quality operators usually are not able to evaluate the relative weight of an item related to the other items, but they can evaluate very well the weight / importance of a quality item related to the overall work package quality. So the technological quality of a quality item is quantified with a score, called Quality Index, from 1 to 10, where 1 means no effect at all on final quality and 10 is a direct strong influence of the quality of the item on the final quality of the work package.

The smaller the Work Packages are, the more flexible and accurate the control will be. As the C/CSC guide and updated research states [15, 16], the control (cost) account level is the WP level, the lowest level in which functional responsibility for individual WBS element exists, where cost are accumulated and performance measurement is performed. The relation between the Quality Breakdown Structure (QBS) and the WBS assigns product and process quality requirements to appropriate group of activities of a Work Package. This relationship may be visualized as a matrix with the quality elements of the QBS listed in one axis and the applicable WBS elements listed in the other. The intersection between these two elements of the matrix is the quality control points, if applicable (Figure 2). The PMBOK [19] defines the control point as the point of the WBS in which the

integration of scope, budget, actual cost, and schedule takes place, and where the measurement of project performance will occur, even on a quality basis. So the Quality Breakdown Structure (QBS) of a construction project enables the objective evaluation of the overall construction quality through quality items measurement. The development of a QBS for a construction project provides the capability of estimating the overall construction quality performance at both the activity and the project levels being in relation to the WBS (Fig. 1 and Fig. 2).

Quality estimate of a construction activity is performed through quality indexes evaluation of each quality item defined for the Work Package of the QBS that include the activity. The definition of quality items for each WP is developed by means of the ISO 9001 Quality Plan for the specific construction project. Table 2 shows quality items for the example of the reinforced concrete Work Package. Quality items should be quantifiable or measurable and are related to both product quality and process quality. Product quality items are related to quality performance of the finished product or sub-product of the activity, while process quality items are related to quality performance of production sub-process of the activity, i.e. operation procedures for quality or safety, e.g. concrete vibration, bricks wetting before placing or fall protection devices for bricklayers. In Table 2 the finished concrete quality item is comprehensive of concrete vibration and cast in place. Table 3 shows the building site organisation WP which has only process related quality items. The quality items of each WP are weighted with a score (Bi,j) from 1 to 10, where a weight of 10 means the maximum estimated effect of the quality item on the overall quality of the activity. As previously said experience shows that quality supervisors are not able to weight the single items between each other and set a percentage of contribution to the work package quality as it is done at the project level, but they can mark the influence of the good quality of the item to the overall quality of the Work Package with a score meaning to what extent good or poor quality of the item causes good or poor quality of the WP itself. The weight is also evaluated in relation to relevant building law and regulations, and in relation to project documents and specification [8].

TABLE II SAMPLE PROJECT: REINFORCED CONCRETE WORK PACKAGE QUALITY EVALUATION (QI), PRODUCT AND PROCESS QUALITY

WORK PACKAGE: Structural work: reinforced concrete

j	Quality item (j)	Weight of item (Bi,j)	Quality Index (Qi,j)	Quality Index weighted (Qwi,j)	Work Package Quality Performance (Qi)
1	Concrete Quality	10	100%	10	
2	Finished Concrete	8	80%	6,4	
3	Rebar	8	95%	7,6	
4	Formwork	7	80%	5,6	
	Total	33		29,6	**90%**

TABLE III SAMPLE PROJECT: BUILDING SITE ORGANISATION WORK PACKAGE QUALITY EVALUATION (QI), PROCESS QUALITY

WORK PACKAGE: Building Site Organisation

j	Quality item (j)	Weight of item (Bi,j)	Quality Index (Qi,j)	Quality Index weighted (Qwi,j)	Work Package Quality Performance (Qi)
1	Building Site layout	8	80%	6,4	
2	Fence/Safety Signals	8	75%	6	
3	Building Site electrical plant	10	90%	9	
4	Scaffolds/fall protection	10	95%	9,5	
5	Tower Crane installation	10	90%	9	
	Total	46		39,9	**87%**

The quality index (Qij) for the quality item (j) of the work pack (i) is evaluated with two alternative methods:

- the percentage calculated with the ratio of the number of positive tests and the total number of tests executed meeting project quality specifications;
- the percentage of adherence to specification estimated by the quality control function.

The actual quality performance is recorded before corrective actions implementation and/or reworking of the defective element.

Then the quality index weighted (Qwi,j) is calculated with the following Equation (2):

$$Qwi,j = Bi,j \times Qi,j \quad (2)$$

where Qwi,j = Quality index weighted, of the item (j) of the WP (i); Bi,j = weight of the quality item (j) on the overall quality of the WP (i); Qi,j = Quality index (j) of the WP (i).

The Quality Performance of the Work Package (Qi) is estimated as the percentage of satisfaction of the requirements of the quality index with their weights, estimated as the sum of the actual quality index weighted with the following Equation (3).

$$Qi = \frac{\sum_{j}^{k} Qwi, j}{\sum_{j}^{k} Bi, j} \times 100 \quad (3)$$

where Qi = Quality Performance of the WP (i); Qwi,j = Quality index weighted of the item (j) of the WP (i); Bi,j = weight of the quality item (j) on the overall quality of the WP (i); k = number of quality items (j) of WP (i); (e.g. Tables 2 and 3).

V. QUALITY KPI FOR CONSTRUCTION PROJECT: DEVELOPMENT AND SAMPLE APPLICATION

The Quality KPI, representing the overall quality of the Construction Project, is estimated as the sum of the quality of each Work Package of the project weighted to represent the importance and contribution of the quality of every Work Package to the overall quality of the project.

As previously said the weight of each Work Ppackage is evaluated with a compromise between the cost proportion and aesthetic and functional consideration, and it is specific for the single construction project.

The evaluation of the quality KPI is a dynamic procedure of project control that estimates at each time-now and at the end of the Project the adherence of construction processes and products with project quality specifications. At each as-of date (t) and at the project completion the quality KPI can be estimated with the Equation (4).

$$Q(t) = \sum_{i=1}^{n} Ai \times Qi \quad (4)$$

where Q(t) = estimated quality KPI of the construction project through the as of date (t); Ai = relative weight of the quality of Work Package (i) to the overall project quality; Qi = quality performance of Work Package (i); n= number of Work Packages (i) of the construction project.

Table 3 shows relative weights of the activities of the sample project.

If, corrective actions to improve project quality are implemented after the quality assessment at the as-of date (t), then the quality KPI should be updated to be adherent to real project status.

By loading quality performance to project schedule it is possible to assess quality performance of the construction project through the as-of date, so the reporting system of the project status can also cover quality information. Table 4 shows project sample Quality KPI (Q) evaluation for the reporting system at project completion.

TABLE IV SAMPLE PROJECT: CONSTRUCTION QUALITY KPI (Q) AT PROJECT COMPLETION

PROJECT QUALITY KPI (Q)	WP WEIGHT (Ai)	WORK PACKAGE DESCRIPTION	WORK PACKAGE QUALITY PERFORMANCE (Qi)
	3,0%	BUILDING SITE ORGANISATION	87%
	5,0%	REINFORCED CONCRETE	90%
	5,0%	WOODEN FLOOR CONSTRUCTION	90%
	15,0%	WOODEN ROOF CONSTRUCTION	90%
	2,5%	EXTERNAL WALL	85%
	2,0%	INTERNAL WALL	85%
	3,0%	ROOF COVERING	88%
	4,0%	PLASTER FINISH	90%
	7,0%	FLOORS AND WALLS TILED FINISH	90%
	2,0%	PAINTINGS	93%
	17,0%	PLUMBING AND SANITARY WORK	85%
	10,0%	ELECTRICAL WORKS	92%
	2,0%	THERMAL AND SOUND INSULATION	90%
	3,0%	SITE IMPROVMENTS	88%
	2,0%	DEMOLITION	77%
	17,0%	DOORS AND WINDOWS	94%
	0,5%	EARTHWORKS	90%
89,4%	100,0%		

VI. CONCLUSIONS

Project performance measures like KPIs are of paramount importance for Project Managers and Stakeholders in Project Control. In construction projects time and cost related KPIs are well known indexes to assess project status, but because of construction project complexity quality-related KPIs are of difficult evaluation.

The basic tool for construction project overall quality estimate proposed is the Quality Breakdown Structure which is composed of different quality related Work Packages. The quality KPIs of each WP can be easily estimated by project control team and with the QBS hierarchical structuring it is possible to estimate overall project quality and the related Quality KPI.

The overall quality performance assessment approach described is an efficient method that views project quality performance as a weighted sum of quality performance of the Work Packages of the whole construction project. Quality

performance of single Work Package is estimated as a weighted sum of quality indexes related to performances of each quality item component of the Work Package.

The found Quality KPI is dependent on the technology – related quality of individual activities, i.e. construction elements, but really the overall quality of a building is not a simple sum of the quality of subparts but it depends also on the relation – quality between subparts, and it is the synthesis of all of these contributions that develops the building quality concept. This is the way forward to Quality KPIs estimation of future research.

REFERENCES

[1] J.K. Galbraith, The New Industrial State, reprint, Princeton University Press, U.S reprint 2007.

[2] H. Kerzner, Project-Based Metrics, KPI and Dashboards, John Wiley & Sons, New Jersey, U.S. 2011.

[3] D. Parmenter, Key Performance Indicators, John Wiley & Sons, New Jersey, U.S. 2007.

[4] Key Performance Indicators (KPI) Working Group, "KPI report for the Minister of Construction", Department of the Environment, Transport and the Regions, London, U.K. 2000.

[5] M. M. Kumaraswamy, and A. Thorpe, "Systematizing construction project evaluations", Journal of Management in Engineering, 12 (1), 1996 pp. 34-39.

[6] S. J. Suk, B.G. Hwang, J. Dai, C.H. Caldas and S. P. Mulva "Performance Dashboard for a Pharmaceutical Project Benchmarking Program", Journal of Construction Engineering and Management, 138 (7), 2012 pp. 864-876.

[7] A. Baraghini "Il piano della qualità nel cantiere di lavori pubblici: aspetti normativi e operativi" Tesi di laurea in Ingegneria Edile, University of Bologna (unpublished) 2006 .

[8] T. Bernardi "Il controllo integrato di tempi/costi/qualità nei cantieri edili: caso di studio" Tesi di laurea in Ingegneria Edile, University of Bologna (unpublished) 2012.

[9] M.A., Bragadin "Quality management in edilizia" INARCOS n.598 aprile 1999 pp193-200.

[10] Building and Construction Authority "CONQUAS The BCA Construction Quality Assessment System", Building and Construction Authority, Singapore 2008.

[11] K. El-Rayes, A. Kandil, "Time-Cost-Quality Trade-Off Analysis for Highway Construction", Journal of Construction Engineering and Management, 131 (4), 2005, pp. 477-486.

[12] A. Kandil, and K. El-Rayes, "MACROS: Multiobjective Automated Construction Resource Optimization System", Journal of Management in Engineering, 22 (3), 2006 pp. 126-134.

[13] S.D. Anderson and J.S. Russel, Guidelines for Warranty, Multi-Parameter, and Best Value Contracting, Transportation Research Board, U.S. 2001.

[14] R.E. Minchin, and G.R. Smith, Quality-Based Performance Rating of Contractors for Prequalification and Bidding Purposes, National Cooperative Highway Research Program NCHRP, U.S. 2001.

[15] T. Rajiani Devi, V. Shobha Reddy, "Work Breakdown Structure of the Project" Internationa Journal of Engineering Research and Applications (IJERA) Vol.2, Issue 2, Mar-Apr 2012, pp. 683-686.

[16] J.J. Moder, C.R. Phillips and E.W. Davis, Project Management with CPM, PERT and Precedence Diagramming Method, Van Nostrand Reinhold Company, New York, Third Edition 1983.

[17] W.J. Rasdorf and O.Y. Abudayyeh "Cost and Schedule Control Integration: issues and needs" Journal of Construction Engineering and Management, ASCE Vol.117 No.3, 1991, pp.486-502.

[18] M.A. Bragadin La Programmazione dei lavori con i metodi reticolari, Maggioli Editore 2011.

[19] Project Management Institute, A guide to the Project Management Body of Knowledge (PMBOK guide), Project Management Institute, Pennsylvania USA 2004.