TU1406
COST ACTION

WG2 and WG3 WORKSHOP

Bridge performance goals and quality control plans

PROJECT PERFORMANCE APPRAISAL FRAMEWORKS AS BLUEPRINTS FOR BRIDGE QUALITY CONTROL

Dimosthenis Kifokeris – Ph.D. Candidate, Aristotle University of Thessaloniki, Faculty of Engineering, School of Civil Engineering, Greece
Yiannis Xenidis – Assistant Professor, Aristotle University of Thessaloniki, Faculty of Engineering, School of Civil Engineering, Greece

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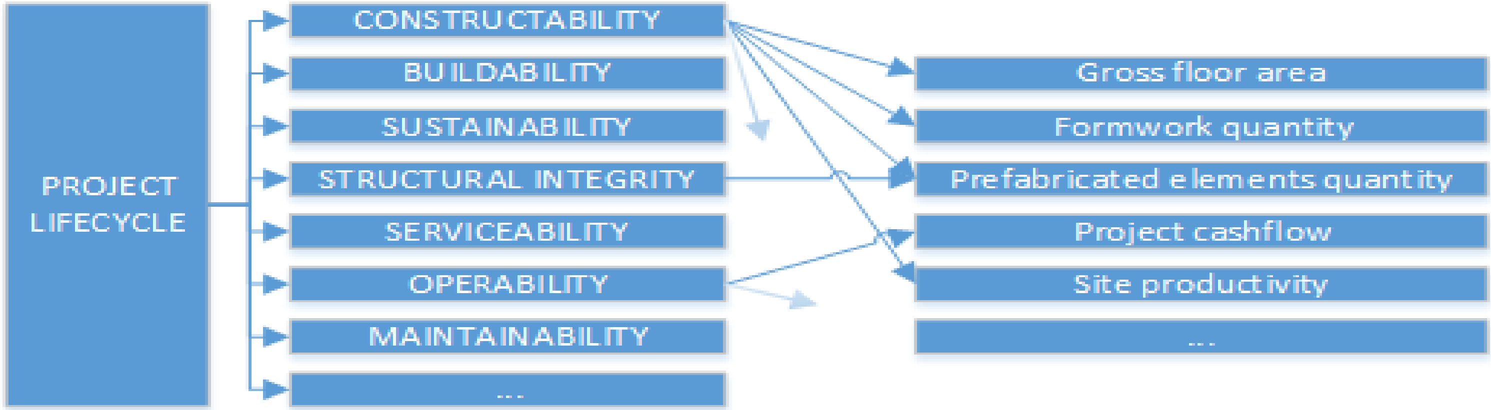
PROJECT PERFORMANCE APPRAISAL FRAMEWORKS (PPAFs) – GENERAL REMARKS (1/2)

- Products of research efforts and the development of cognitive, mathematical and software tools
- Developed and established in practice by agents of the AEC industry and/or national institutions, authorities and regulations
- Utilized in all kinds of projects (buildings, infrastructure and special project cases)

PROJECT PERFORMANCE APPRAISAL FRAMEWORKS (PPAFs) – GENERAL REMARKS (2/2)

- Implemented, simultaneously or separately, in:
  - The monitoring of the full project lifecycle
  - The evaluation of distinct project lifecycle notions (e.g. constructability, buildability, sustainability, structural integrity, serviceability, operability, maintainability etc.)
  - The computation of constituents of the project lifecycle notions (e.g. gross floor area, formwork quantity, prefabricated elements quantity, project cash flow, site productivity etc.)



PRESENTED PPAFs

- CONQUAS (CONstruction QUality Assessment System) – Singapore
- PASS (Performance Assessment Scoring System) – Hong Kong
- BDAS (Buildable Design Appraisal System) – Singapore
- BAM (Buildability Assessment Model) – Hong Kong
- SBTool – Portugal, Spain & Italy

CONstruction Quality Assessment System (CONQUAS) (1/2)

Table I. Items assessed regarding structural frame

Item	Points
Formwork	5
Reinforcement	10
Finished concrete	15
Concrete quality	8
Reinforcement quality	2

Table II. Items assessed regarding architectural works

Item	Points
Floors	8
Internal walls	8
Ceiling	4
Doors and windows	4
Rainwater down-pipes, plumbing, sanitary fittings	3
Installation of mechanical and electrical services	3
Components (permanent fixtures)	3
Roof	5
External walls	6
Material and functional tests	6

Table III. Items assessed regarding facilities of external works

Item	Points
Aprons and drains	2
Roadworks and carparks	2
Footpaths and turfing	2
Fencing and gates	2
Other areas, specific to the project	2

Checklist of the CONQUAS scoring system

- Developed by the Construction Industry Development Board (CIDB) of Singapore and compulsorily in effect since 1989
- Appraises the quality of public sector *buildings* in terms of (i) the **structural frame**, (ii) the assorted **architectural works** and (iii) the **external works**
- A scoring system with a checklist related to aspects (i)-(iii) is utilized by state evaluators to produce the CONQUAS score for the whole building and/or certain elements of it

CONstruction Quality Assessment System (CONQUAS) (2/2)

- Showcases validated positive correlations with site productivity
- Incorporates scoring thresholds that grant tendering advantages to contractors achieving or surpassing them

Bonus/Discount Threshold Scores (1/4/2016 to 31/3/2017)

Building Category	Bonus Threshold Score for FY16	Discount Threshold Score for FY16
Residential	91.3	85.3
Commercial	92.9	86.9
Institution	89.2	83.2
Industrial/Others	85.9	79.9

- Appraises **finished projects** and focuses on the **classification of contractors**
- Followed by the establishment of CE CONQUAS for various, and not only building, public sector projects (e.g. sewage networks, marine structures etc.)

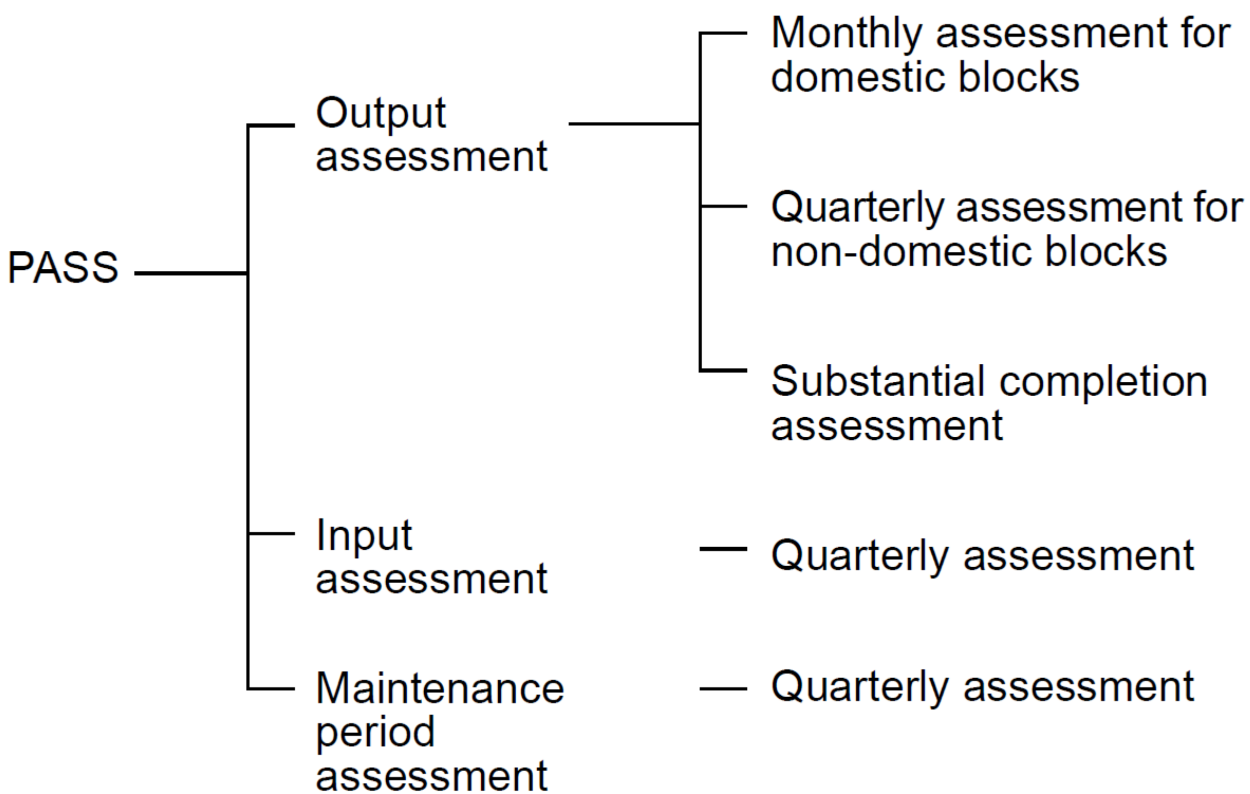
Performance Assessment Scoring System (PASS) (1/2)

- Adapted from CONQUAS for Hong Kong and in effect since 1990
- Utilizes a similar to CONQUAS scoring system (with similar categories (i)-(iii), but also an additional category (iv) **other obligations**)

- Apart from completed buildings, also monitors **projects currently under construction**, *taking into account*
  - the contractor's managerial performance
  - the contractor's productivity
  - the contractor's conformance to the specified quality thresholds

  and allotting points for
  - the management, organization, coordination and control of works
  - the resources flow
  - the real-time schedule progress
  - the project documentation

Performance Assessment Scoring System (PASS) (2/2)



PASS schema hierarchy

The depicted output assessment is related to the score of construction itself, and the input assessment to the productivity and managerial notions

Buildable Design Appraisal System (BDAS) (1/2)

- Developed by the Building and Construction Authority (BCA) of Singapore
- Put in effect complimentarily to CONQUAS since the mid-’90s. The two form a composite project quality and performance assessment framework, primarily targeted to *high-rise buildings*

- Appraising the conformance of building designs to the notion of buildability as “the extend to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building”, for
  - better practical integration of design and construction
  - better deliverables
  - fewer discrepancies between the as-designed and as-built project states
  - more thorough satisfaction of the defined project objectives

Buildable Design Appraisal System (BDAS) (2/2)

Buildability Score of Building	**=**	**Buildability Score of Structural System (including Roof System)** **+ Buildability Score of Wall System** **+ Buildability Score of Other Buildable Design Features** **+ Bonus Points**
BScore (In mathematical terms)	**=**	**$50[\sum(As \times Ss)] + 40[\sum(Lw \times Sw)] + N$ + Bonus points**
where As	=	Asa / Ast
Lw	=	Lwa / Lwt
Aw	=	Awa / Awt
As	=	Percentage of total floor area using a particular structural design
Ast	=	Total floor area which includes roof (projected area) and basement areas
Asa	=	Floor area using the particular structural design
Lw	=	Percentage of total external & internal wall length using particular wall system
Lwt	=	Total wall length excluding external basement wall for earth retaining purpose
Lwa	=	External & internal wall length using particular wall system
Aw	=	Percentage of total external & internal wall areas using particular wall design
Awt	=	Total wall area, excluding perimeter wall of the basement. All internal walls in the basement are to be considered.
Awa	=	External & internal wall areas using particular wall design
Ss	=	Labour saving index for structural design
Sw	=	Labour saving index for external & internal wall design
N	=	Buildability Score for other buildable design features
Bonus points	=	Bonus points for single integrated components

The BDAS scoring system

- The scoring system measures, classifies and awards points to the buildability attributes of construction designs
- The 3S principle is promoted:
  - Standardization (e.g. repetition of grids, component sizes and connection details)
  - Simplicity (utilization of construction systems and connection details of low complexity)
  - Single integrated elements (combination of multiple components to form composite elements)
- There are validated positive correlations between high BDAS and high CONQUAS scores

Buildability Assessment Model (BAM) (1/2)

- Adapted from BDAS for Hong Kong in the early ’00s
- PASS and BAM form a composite project quality and performance assessment framework, primarily targeted to *buildings*

- Extends the 3S principle of BDAS into nine buildability factors (BFs):
  - BF1: economic use of the contractors’ resources
  - BF2: easy visualization and coordination of design requirements by the site staff
  - BF3: development and adoption of alternative construction details
  - BF4: overcoming of restrictive site conditions
  - BF5: standardization and repetition
  - BF6: freedom of choice between prefabricated and on-site works
  - BF7: simplification of construction details in case of non-repetitive elements
  - BF8: mitigation of adverse weather impact by enabling flexible construction schedules
  - BF9: consideration of site work sequencing in the designs

Buildability Assessment Model (BAM) (2/2)

Construction Systems

Structural frames	$23\ \Sigma(V_s \times BI_s)$
Slabs	$14\ \Sigma(A_s \times BI_s)$
Envelopes	$19\ \Sigma(A_e \times BI_e)$
Roof	$19\ \Sigma(A_e \times BI_e)$
Internal walls	$3\ \Sigma(A_{iw} \times BI_{iw})$

Proportionate area using a particular finishing system in a particular location i.e. ceilings, internal walls, internal floors, external walls or roof coverings

Buildability Index for particular finishing system in a particular location i.e. internal ceilings, internal walls, internal floors, external walls or roof coverings

Finishing systems	$2\ \Sigma(A_f \times BI_f)$
Building features	$5\ \Sigma(BI_{bf} \times cov_{bf}) \div$ Sum of BI_{bf}
Building services aspects	$2\ \Sigma(BI_{bs} \times cov_{bs}) \div$ Sum of BI_{bs}
Site specific factors	$12\ \Sigma\ BI_{ss} \div$ Sum of applicable BI_{ss}
Innovative ideas of improving buildability	**10** (max.)

Total buildability score = 100 (max.)

BI_{bf}: Buildability Index for a particular building feature

BI_{bs}: Buildability Index for a particular building services aspect

Bi_{ss}: Buildability Index for a particular site specific factor

Cov_{bs}: Coverage of the building feature (in %)

The BAM framework

SBTool (1/3)

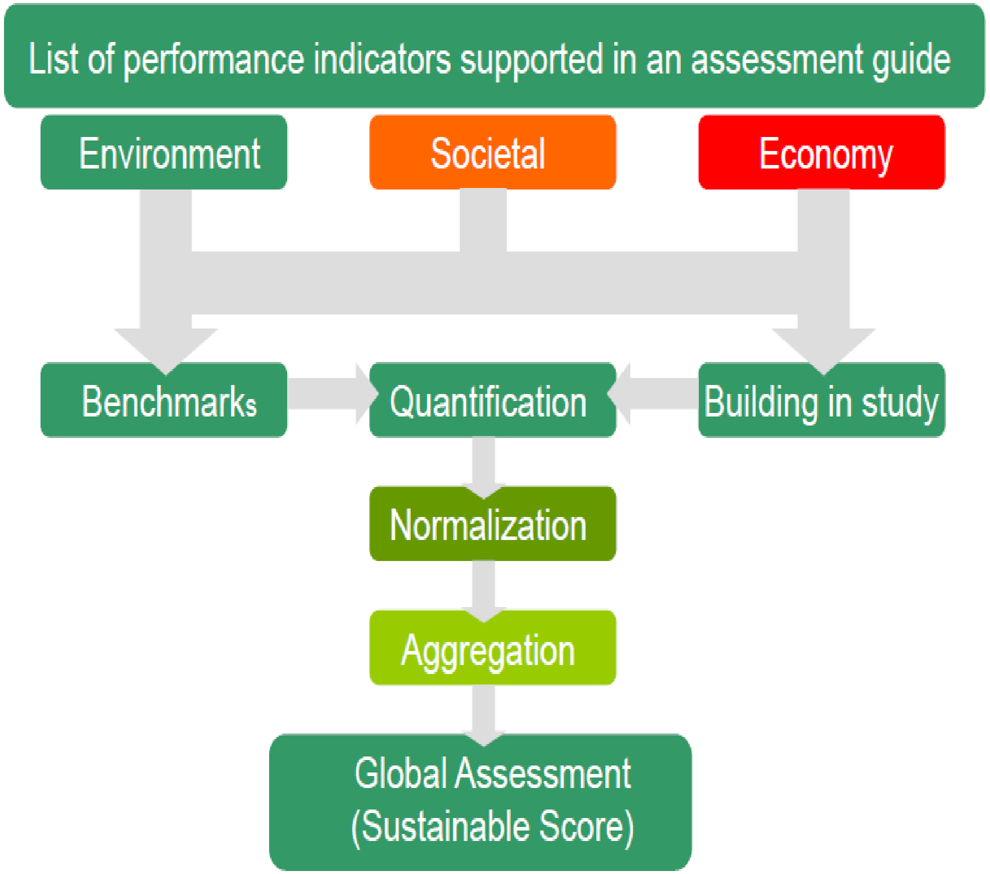
- Developed by iiSBE in 2007, overhauling the previous tool GBTool
- Customized and adapted for use in Portugal, Spain and Italy for the sustainability performance assessment both of *sites* and *building projects*

- Used primarily by:
  - authorized organizations (e.g. municipalities, non-governmental organizations (NGOs) etc.) for the establishment of rating systems suiting specific regions and building types
  - owners and managers of large building portfolios to specify their performance requirements to their staff and consultants
  - educators of graduate engineering students

- Takes into account sustainability performance indicators (SPIs), **discretized** by:
  - the social sustainability dimension
  - the environmental sustainability dimension
  - the economic sustainability dimension

  and **benchmarked** through the principles of:
  - conventional practice
  - best practice

SBTool (2/3)



The SBTool methodology

Features a top-down layout:

- a core framework encompassing established, regional and generic sustainability standards, requirements, thresholds and specifications
- separate and targeted computational sheets producing the sustainability score of specific projects

SBTool (3/3)

$$\overline{P}_i = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i$$

with,
P_i – Value of *i*th parameter;
P_{*i} – Conventional practice of *i*th parameter;
P^*_i – Best practice of the *i*th parameter.

	Grade	Range
	A+	$\overline{P} > 1,00$
Best practice	A	$0,70 < \overline{P} \leq 1,00$
	B	$0,40 < \overline{P} \leq 0,70$
	C	$0,10 < \overline{P} \leq 0,40$
Conventional practice	D	$0,00 \leq \overline{P} \leq 0,10$
	E	$0,00 < \overline{P}$

The indicator value normalization equation and the graded scale of the SBTool

- In the resulted sustainability score, the performance values obtained for each parameter and indicator are normalized on a scale between 0 (reference/conventional value) and 1 (best performance)
- The quantified values are converted in a graded scale, from A+ to E (sustainability grade of the project)

INTEGRATION OF KBPIs AND PPAFs (1/2)

- WG1 of TU1406 discretized Key Bridge Performance Indicators (KBPIs) utilizing five homogenized categories:
  - Defects corresponding to the KBPIs
  - Relations of the KBPIs to certain parameters (material properties, equipment and protection, geometry changes, bearing capacity, structural integrity and joints, original construction sequence and design, dynamic behavior, environmental exposure)
  - Rating of the KBPIs
  - Cost and importance of the KBPIs
  - Loads corresponding to the KBPIs

- All the presented PPAFs utilize indicators discretized in categories, databases in checklist format and inclusive computational methodologies

INTEGRATION OF KBPIs AND PPAFs (2/2)

- The presented PPAFs, integrated with the KBPIs, could serve as blueprints and practical examples of appraising frameworks **for a possible validation of the methodology developed by WG2 of TU1406**

- Possible modifications for any of the presented PPAFs to be used as validation drafts for WG2:
  - Swapping the overhead system categories with the five homogenized KBPI ones
  - Substituting the corresponding indicators with the KBPIs
  - Adapting of the weight/point allocation scheme
  - Adapting of the computational, normalized and interface-related elements

CONCLUSIONS (1/2)

- PPAFs already used in practice can provide valuable data concerning best practices and lessons-learned for the appraisal of project performance and quality

- Case studies and applicational examples of such frameworks, especially those easily adaptable for infrastructure projects and lifecycle performance (including sustainability and quality), should generally be collected, scrutinized and serve as validation blueprints for:
  - The establishment of the performance goals
  - The computational schema of a QC plan for bridges
  - The reclaiming of past experience
  - The more efficient dealing with problematic or bottlenecking aspects that may arise during the conceptualization and construction of a QC plan for bridges

CONCLUSIONS (2/2)

- Of the presented PPAFs, SBTool seems the most suitable for the validation purposes, since
  - it is the only sustainability-oriented PPAF, thus offering a head start for the sustainability considerations related to the KBPIs
  - it is the only adapted and validated in practice in Europe
  - its mathematical schema ensures that as many KBPIs as desired can be used, because all elements are in the end normalized into a single scale – no substitution is required, and all KBPIs can be taken into account in addition to the already existent SBTool indicators (if such a thing is deemed necessary)
  - its versatility ensures an easier adaptation to infrastructure projects
  - it is more robust, because it relies not only on expert input, but also in: (i) specific mathematical methodologies like multivariate and linear regression and (ii) machine learning schemes like artificial neural networks

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Images in slide 2 taken, respectively, from:

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