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Control panel and indicators for production control in building projects

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Abstract: In general, every project should have indicators that monitor compliance with established goals. In construction projects, there are a large number of indicators proposed by many researchers; however, an analysis of the state of the art shows a frequent confusion between Result, Process and Leading Indicators.

This paper, which is an extended version of the paper submitted by the same authors at the Creative Construction Conference 2017 and published in *Procedia Engineering* (DOI: 10.1016/j.proeng.2017.07.230), presents a proposal of these three types of indicators for the design, supply and assembly phases of housing projects. Thus, all project stakeholders can have a control panel that will monitor if an indicator exceeds the limits, thereby allowing taking corrective actions in a timely and effective manner.

Keywords: benchmarking, continuous improvement, lagging indicators, leading indicators, key performance indicators

1 Introduction

After project execution, every project requires Result Indicators to confirm if the goals set at the beginning were met. These indicators will serve as feedback for future projects and to complete the continuous improvement cycle. Furthermore, similar to the crew members of a ship who need to know if they are on the right course throughout the journey, the project team needs Process Indicators to make sure that the project—during its development—is moving towards the expected goals. In this way, if we are deviating from these goals, we can make necessary and timely corrections. As these indicators are obtained at a certain period of time after execution, they are known as post-mortem; thus, it is necessary to use Leading Indicators that will help achieve the expected goals.

The review of the current state of indicators in the construction sector shows that it is usual to mistake these three types of indicators in literature. For this reason, this article proposes a Control Panel with a Result Indicators group oriented to building projects, and it then develops the Process and Leading Indicators for each phase of the project.

2 Current state of performance indicators in constructions

Performance measurements in the construction industry have been carried out under different approaches, such as Enterprise performance measurements, Project performance measurements and Benchmarking Programs, over the past two decades (Suk et al. 2012). Besides this classification, the indicators used in such measurements can be divided into Result Indicators, Process Indicators and Leading Indicators.

2.1 Enterprise and project indicators

Enterprises were evaluated using financial and accounting indicators until the introduction of the Balanced Scorecard (Kaplan and Norton 1992), in which user, innovation and internal process indicators were taken into account (Suk et al. 2012). Additionally, enterprises are based on projects and they have their own indicators to measure the level of compliance with established goals; nevertheless, a better differentiation among Process, Result and Leading Indicators is needed.

2.2 Result indicators

Result Indicators seek to evaluate goal achievement or the achievement of expected results. Their report must be submitted to the project owner and the top management

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(Alarcon et al. 2001). They can refer to both internal (at the end of each phase) and final (at the end of the project) results.

2.3 Process indicators

Process Indicators seek to measure the development of activities related to the necessary processes to obtain the final product, that is, the building. In other words, they seek to evaluate the steps to reach the goal, such as design, construction, planning and procurement (Alarcon et al. 2001).

2.4 Leading indicators

Leading Indicators are related to proactive or preventive actions; they can be used as predictors of future performance levels of any project's aspect (Toellner 2001; Hinze et al. 2013). In other words, Leading Indicators measure variables that are known to be related to certain Result and Process Indicators (Jablonowski 2011). However, unlike these indicators, which are post-mortem, Leading Indicators can be obtained timely to take corrective actions.

2.5 Benchmarking programs

Benchmarking is a tool to identify the performance in all kinds of enterprises and projects, and it is also used by construction companies (El-Mashaleh et al. 2007). Benchmarking programs are divided into internal benchmarking, when it comes to projects within the same company, or external benchmarking, which refers to other companies or other projects from other companies (National Research Council 2005).

In any case, benchmarking programs should be carried out using Result Indicators, since Process Indicators are not definitive and may lead to wrong comparisons.

Some examples of these initiatives are the UK Construction Key Performance Indicators (2000); the National Benchmarking System for the Chilean Construction Industry developed by the Technological Development Corporation, CDT (2001); the US CII Benchmarking and Metrics developed by the Construction Industry Institute, CII (1993); and the *Sistema de Indicadores de Qualidade e Produtividade para a Construção Civil, SISIND* from Brazil (1993). In 2004, the initiatives were analyzed, identifying difficulties or problems related to each one of them (Costa et al. 2004). Among the difficulties faced by these researchers, we have the lack of relationship between all the metrics, the uncertainty that the necessary information will be available, the use of indicators that are hard to measure, the lack of integration between indicators and critical processes and the lack of training in the implementation of measurement systems.

In 2013, as a part of the creation of a benchmarking system in Saudi Arabia, the King Saud University gathered indicators from enterprises and construction projects based on the existing research studies worldwide. Some of the institutions included in this research were the CII (United States), the Department of Environment, Transport and the Regions (DETR) from UK, and the Technical Development Corporation from Chile (Ali et al. 2013).

In addition to the differences presented by Costa et al., it must be pointed out that the abovementioned benchmarking initiatives does not consider the entire life cycle of a project. They usually focus on the construction phase and neglect project monitoring in early stages, which are critical to the success of the project. Furthermore, they lack a clear differentiation between the abovementioned indicators.

2.6 Inventory of construction project indicators

One of the main conclusions drawn from the final list of Project Indicators identified by Ali et al., and other articles reviewed for this study is that all authors mix different kinds of indicators. For this reason, it is important to identify the Result Indicators first, so that they serve as a guide to identify and structure Process and Leading Indicators.

Table 1 shows a list of indicators—properly classified in this article—organized by its corresponding classification and a consolidated table of both types of indicators.

3 Control panel proposal

Based on the aforementioned information, besides classification by the type of indicators, it was necessary to place them in the life cycle phase and in the corresponding success criteria; therefore, a biaxial control panel structure is proposed to modify the one presented in the previous research study by the same authors.

Tab. 1: Classification and inventory of result, process and leading indicators (Orihuela et al. 2016)

References	Number of indicators		
	Total	Results and process	Leading
Jastaniah (1997)	9	5	4
Egan (1998)	7	5	2
KPI Working Group, (2000)	7	5	2
Alarcon et al., (2001)	13	6	7
Pillai et al., (2002)	8	3	5
Wong, (2004)	8	4	4
Cheung et al. (2004)	8	5	3
Ramírez et al. (2004)	9	5	4
Da Costa et al. (2006)	7	4	3
Botero et al. (2007)	10	7	3
Kim and Huynh (2008)	8	4	4
Rankin et al. (2008)	8	7	1
Skibniewski and Ghosh (2009)	4	3	1
Roberts and Latorre (2009)	9	6	3
Toor and Ogunlana (2010)	9	5	4
CII Construction Industry Institute (2011)	6	3	3
Kunz and Fischer (2012)	9	6	3
Constructing Excellence (2013)	16	7	9
Consolidated list of result and process indicators			
1. Client Satisfaction 2. Safety 3. Claims 4. Construction Cost 5. Construction Lead Time 6. Finance 7. Environment 8. Materials 9. Social 10. Stakeholders Satisfaction 11. Specification Compliance 12. Scope Changes			
Consolidated list of leading indicators			
Planning, Staff Experience, Communication, Rewards, Time, Productivity, Defects, Risks, Effectiveness of decisions, Client Commitment, People, Subcontract Management, Innovation, Equipment Performance, Changes in Processes, Disputes, Re-work, Stakeholders Integration, Quality Administration, Materials Administration, Equipment and Machinery, Suppliers, Company Management, Training, Resources Efficiency, Workforce.			

3.1 Vertical structure of the control panel

For many years, three success criteria corresponding to the Iron Triangle (cost, time and quality) were considered as ideal elements to achieve the success in a project. However, recent research studies include other aspects such as safety, environment and customer satisfaction (Suk et al. 2012; Ward et al. 1991; Atkinson 1999).

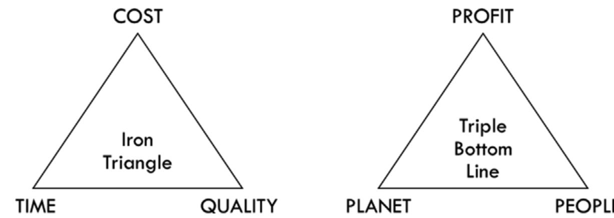

Fig. 1: Iron Triangle and the Triple Bottom Line.

Nowadays, with the help of several reports made by entities concerned about sustainability, it is known that projects should consider three aspects during their life cycle: Society, Environment and Economy. For this reason, we believe that the vertical structure of the control panel should be composed of five criteria: Cost, Time, Quality, Environment and Society. The previously described structure is presented in Figure 1.

Regaring the environmental issue, there are many models focussed on the certification of sustainable buildings in the world, which cover the environmental aspect quite well although they do not fully cover the triple bottom line. A comparison between some well-known certification systems such as LEED, BREEAM and GREEN STAR shows that there is a good correlation between their categories (see Figure 2); therefore, it is valid to follow the logic of their rating systems for environmental indicators in each project phase.

3.2 Horizontal structure of the control panel

Given that the development of construction projects takes longer time, it is important to not only use a general Result Indicator for the project but also include Result Indicators per phase. Figure 3 shows the project phases by different sources.

The five life cycle phases proposed by Lean Project Delivery System are used in the control panel.

3.3 Control panel proposal

Figure 4 shows the biaxial control panel proposal. In the Project Definition Phase, the baselines of these indicators must be defined, and in the Use Phase, compliance must be ensured. In the Design, Supply and Assembly phases, this Control Panel shows a group of Result Indicators by each phase.

SYSTEM	CATEGORIES										
LEED	Integrative Process	Location & Transportation	Materials and Resources	Water Efficiency	Energy & Atmosphere	Sustainable Sites	Indoor Environment	Innovation	Regional Priority		
BREEAM	Management	Transport	Materials	Water Efficiency	Energy	Land Use & Ecology	Health and Wellbeing	Innovation		Pollution	Waste
GREEN STAR	Management	Transport	Materials	Water	Energy	Land Use & Ecology	Indoor Environment	Innovation		Emissions	

Fig. 2: Sustainable construction certification systems. (Building Research Establishment 2016; Green Building Council of Australia 2017; US Green Building Council 2013).

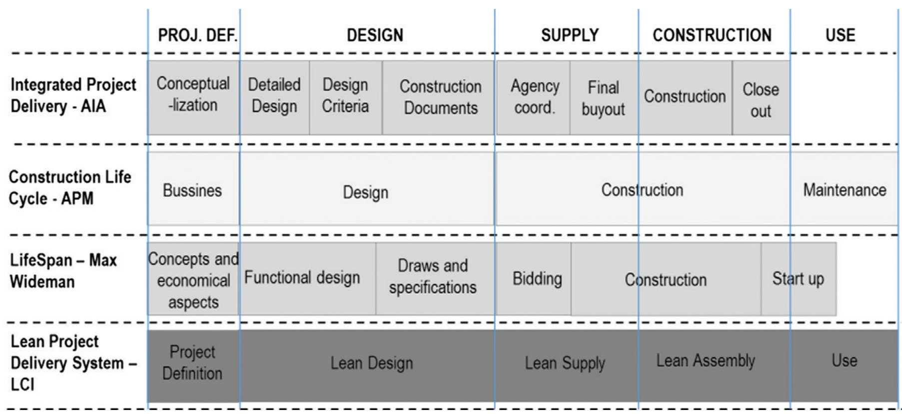

Fig. 3: Project phases by different sources. (American Institute of Architects 2007; Ballard 2008; Navarro Sánchez 2010; Wideman 2004).

	Project Def.	Design	Supply	Assembly	Use
Time	Indicators Baseline Definition	Design Lead Time	Construction Lead Time		Stakeholders Satisfaction
Quality		User Satisfaction	Quality of Materials	Quality of Execution	
Cost		Construction Target Cost	Construction Cost		
Environment		Environmental Impact	Environmental Supply	Environmenta Execution	
Social Balance		Social Impact	Social Supply	Social Execution	

Fig. 4: Control panel structure and project result indicators adapted from Orihuela et al. (2016).

4 Design phase of housing projects indicators proposal

Due to the abovementioned reasons, we also propose five Result Indicators for the Design Phase, their corresponding Process Indicators, and finally, Leading Indicators that lead and help us achieve the expected goals. Table 2 shows the first two types of indicators: Result and Process Indicators.

4.1 Design lead time indicator

The Result Indicator for the design time measures the relation between the real time and the contractual time for the Design Phase. The design time for a construction project is extremely important in relation to the total time allotted for the project; therefore, it is necessary to verify that the design time does not exceed the time allotted for the project.

Tab. 2: Result and process indicators for the design of housing projects

Criteria	Result indicators	Process indicators
Time	Design Lead Time	Time for Definition of Project Scope Time for Investor Approval Time for Reviewing Entity Approval Time for Interconsultation Latency Time for Design and Plans development
Quality	Projection of Customer Satisfaction	Level of Safety Perception Level of Salubrity Perception Level of Functionality Perception Level of Aesthetics Perception Level of Comfort Perception
Cost	Construction Target Cost	Cost of Structural and Constructive System Cost of MEP Systems Cost of Finishes Level
Environment	Environmental Design	Energy Efficiency Water Efficiency Sustainable Transportation Environment Pollution
Society	Social Design	Compliance with Design Norms Incorporation of Social and Productive Spaces

Process Indicators consider the necessary time to obtain a good general agreement about the scopes of the project, that is, to achieve a correct alignment of the project stakeholders' needs and values. In addition, these indicators consider the response times for investors' approvals, the response times for approvals of the reviewing entity, the periods of latency for consultations between the specialists from the design team and the actual time to develop plans and specifications of all specialties of the design.

The main Leading Indicators that can help us accelerate the project scope definition are the investor's understanding, the designer's experience and the information system used by the people involved in the project scope. Clarity and technical foundation in the proposal for the investor are the Leading Indicators to obtain his approvals as fast as possible. In the same way, compliance with rules and familiarity with the necessary paperwork and formalities are indicators that lead us to obtain the approvals from the reviewing entity. The Leading Indicators proposed in order to reduce inter-consultation latency are the availability, flexibility, promptness and punctuality of project designers and the efficacy of the means of communication. The designers' project experience, clarity of standards and protocol of timely interventions are the indicators proposed to achieve an efficient design and development of plans and specifications.

4.2 Projection of customer satisfaction indicator

This Result Indicator is measured through Customer Satisfaction by comparing the estimation of customer satisfaction level—made by the design team after the plans are completed—with the level of expected customer perception defined in the baseline. The satisfaction of the end user is one of the main goals of any construction project. In the case of housing projects, we will use the Orihuela and Orihuela's (2014) proposal to estimate the end user satisfaction.

Process Indicators consider the possible perception that customers may have about physical safety of the building, salubrity conditions, functionality, aesthetics, and thermal, acoustic, visual and ergonomic comfort.

Some of the most important Leading Indicators are the project designers' experience, continuous and updated training, proactivity, and teamwork.

4.3 Construction target cost indicator

This Result Indicator is measured by the construction cost, by comparing the budget based on the plans and specifications with the target cost of the project.

Process Indicators consider the chosen structural and construction system, the types of installations such as electrical, mechanical, plumbing, gas, communication, air injection, monoxide extraction and fire protection services; and the quality of finishes. All of these decisions determined in the Design Phase will impact the construction final cost.

Some Leading Indicators are the project designers' experience and ability to monitor the costs during the design process, to choose new materials, to evaluate several alternatives, to offer a good level of constructability, to obtain a good compatibilization level and details in plans. All of these will lead to comply with the expected cost of the project.

4.4 Environmental design indicator

This Result Indicator compares the credits of environmental certification obtained in the design with the expected credits for this phase.

Process Indicators consider the energy efficiency, water efficiency, promotion of sustainable transportation and environmental pollution, whose considerations in the design phase reduce the environmental impact.

Some of the Leading Indicators are knowledge of low power and water-saving devices, knowledge of advanced monitoring devices for energy and water consumption, the environmental commitment of project designers and investors' knowledge of green transportation benefits, and knowledge of the reduction of heat islands, light pollution and rainwater management. All of this will contribute to reduce the project environmental impact.

4.5 Social design indicator

This Result Indicator compares the social impact level caused by the design with the level set in the project baseline.

Process Indicators consider compliance with design standards and the availability of spaces for social and productive life.

Some of the Leading Indicators are the professional, ethical and moral responsibility towards compliance with the project designers' and investors' design standards, as well as their good disposition to include spaces that allow people to socialize, relax and practice sports, and flexible productive spaces to promote the creation of cottage industries.

5 Supply phase indicators proposal

Due to the abovementioned reasons, we also propose five Result Indicators for the Supply Phase, their corresponding Process Indicators, and finally, Leading Indicators that lead and help us achieve the expected goals. Table 3 shows Result and Process Indicators.

Tab. 3: Result and process indicators for the supply of housing projects

Criteria	Result indicators	Process indicators
Quality	Quality of Materials and Equipment	Quality of Structural Materials
		Quality of MEP Materials and Equipment
		Quality of Finished Materials
Environment	Environmental Supply	Green Seal Materials
		Sustainable Transportation
Society	Social Supply	Local labor

5.1 Quality of materials and equipment indicator

This Result Indicator compares the specified quality of materials and equipment with the quality gained during the supply phase.

Process Indicators contemplate the quality of structural materials (mainly steel and concrete); the quality of the materials and equipment of sanitary facilities (water pipe network, drainage, and pumping equipment); the quality of the electrical installation materials (lighting network and electrical outlets, wires, electrical panels and wells to ground); the quality of the electromechanic equipment; and, finally, the quality of the main materials of the internal finishes, which have been specified on the blueprints and which largely depends on the target market.

Some Leading Indicators are the purchasing and logistics personnel's knowledge about the technical characteristics of the purchased materials and its true cost/benefit balance, the company's good purchasing policy and a good post-occupancy feedback system on the performance of these materials and/or equipment.

5.2 Environmental supply indicator

This Result Indicator compares the environmental impact caused during the supply of resources of the work with the environmental impact expected, which can be quantified by the environmental credits obtained against the ones expected during this supply phase.

The Process Indicators include the percentage of green seal materials, that is, those products that from the extraction of the raw material until the end of its use fulfil the requirements of environmental efficiency. In addition, they contemplate the percentage of materials used close to the region where the project is done, with which transportation and environmental pollution are optimized. Therefore, it compares the cost of materials that meet these conditions with the total cost of materials.

Some Leading Indicators include knowledge and awareness of the environmental impact generated by some materials throughout their life cycle. These should influence the companies' procurement policies.

5.3 Social indicator supply

This Result Indicator compares the social impact produced by the supply of resources of the work with the expected social impact.

Process Indicators include the generation of local labour, which promotes the well-being and progress caused by the job generation in the communities where the project is being done, not only by direct jobs but also by the generation of complementary work.

Some Leading Indicators are the company's social responsibility and supply policies.

6 Assembly phase indicators proposal

Due to the abovementioned reasons, we also propose five Result Indicators for the Assembly Phase, their corresponding Process Indicators, and finally, Leading Indicators that lead and help us achieve the expected goals. Table 4 shows the Result and Process Indicators.

6.1 Construction lead time indicator

This Result Indicator compares real-time construction with its contractual period; it is one of the most common indicators in construction projects.

Process Indicators include the time required for construction of infrastructure, superstructure and internal finishing.

Some Leading Indicators are the level of knowledge about the project and its constraints, the planner's ability, the team work and the level of commitment of those involved, among others.

Tab. 4: Result and process indicators for the supply of housing projects

Criteria	Result indicators	Process indicators
Time	Construction Lead Time	Time for Infrastructure Time for Superstructures Time for Finishing works
Quality	Construction Quality	Quality of Structure Quality of MEP Systems Quality of Finished
Cost	Construction Cost	Cost of Structure Cost of MEP Systems Cost of Finished
Environment	Environmental Construction	Pollution Wastes Recycling
Society	Social Construction	Legal work Frequency of accidents Occupational diseases

6.2 Construction quality indicator

This Result Indicator compares the quality obtained during the execution of the construction with the quality specified in the blueprints, technical specifications, laws, regulations and standards.

Process Indicators comprise the quality of structure, sanitary installations, electromechanical installations and internal finishing. These indicators must ensure the building good behaviour both in static situation and in dynamic situation. Some Leading Indicators are the training and experience of the different staff crews, good working environment and good communication between different areas, among others.

6.3 Construction cost indicator

This Result Indicator compares the final cost obtained with the contract cost. Together with the lead time of construction, it is the most common indicator in construction projects.

Process Indicators include the cost of structure, facilities and internal finishes.

Some Leading Indicators are the team's ability to minimize wastes, the ability to apply constructability during the construction process, the planners' efficiency, the team work and the team's efficient communication, among others.

6.4 Environmental construction indicator

This Result Indicator compares the environmental impact caused during the work with the environmental impact expected. It can be quantified by the environmental credits against the ones expected during this construction phase.

Process Indicators include pollution prevention during the work, the demolition waste management, the waste reduction management, and the recyclable materials storage and collection.

Some Leading Indicators are the staff's knowledge about environmental standards, investors' awareness and decision to incorporate these environmental policies, among others.

6.5 Social construction indicator

This Result Indicator compares the social impact caused during the work with the expected impact. It seeks to promote, to the extent possible, poverty reduction, labour fulfilment, legal, economic and cultural rights, as well as the respect for the communities and places where the projects are carried out.

Process Indicators include work legality, with which workers can access all their rights for health, retirement pension and legal existence; low frequency of occupational accidents, low frequency of occupational diseases, respect for the inhabitants' tranquillity and rights in the area affected by the project.

Some Leading Indicators include the corporate social responsibility, efficiency of the control systems, awareness of the inherent risks, workers' training and investment in security devices, among others.

7 Limitations

The proposed Control Panel is applicable to construction projects in general; however, some indicators proposed in this paper are only suitable for building or housing projects.

In relation with the methodology, to enlarge the number of indicators collected, a metasearch engine can be used.

8 Conclusions

The review of the state of the art in relation to the indicators of construction projects shows us that there is a random combination of different types of indicators, which does not contribute to obtain a clear and an effective monitoring of the projects in the industry.

First of all, this paper proposes a biaxial control panel that takes into consideration the phases of the project life cycle on one hand and the project success criteria on the other hand. Each one of the Result Indicators of a construction project is included in the control panel.

Then, a group of Result and Leading Indicators are proposed for building projects. The organization of these indicators allows to easily identify where each indicator belongs to, thereby showing on what we focus our improvement efforts. Both these proposals will help us put into practice the monitoring of the construction project based on indicators.

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