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Evaluation of sustainable construction sites: a lean, green and well-being integrated approach

Avaliação de canteiros de obras sustentáveis: uma abordagem Lean, Green e Well-being

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Abstract: This paper proposes a performance evaluation model of sustainability for construction sites. This model was developed bringing together the Lean Construction, Green Building and the Well-being concepts addressed through the triple bottom line concept of sustainability. Following the Design Science approach, the model was applied in three construction sites at the city of Fortaleza, northeast of Brazil. Results are presented to validate the performance evaluation model proposed. It can be observed that the model can handle a range of variables both in terms of possible management actions and in terms of their sustainability outcomes. Different from others performance evaluation models, this artefact takes in consideration actions that are theoretically deemed to promote sustainability (according to particular construction phases) and managerial actions that are actually implemented. Finally, graphical displays help to guide how sustainability might improve over time, either evaluating individual sites against their previous records or benchmarking different building projects among different construction companies.

Keywords: Sustainability; Lean; Green; Well-being; Performance evaluation.

Resumo: Este trabalho tem por objetivo analisar um modelo de avaliação de canteiro de obras sustentáveis desenvolvido a partir da integração das abordagens da Construção Enxuta (*Lean Construction*), Construção Verde (*Green Building*) e um novo conceito – o *Well-being*, que está ligado a dimensão social do tripé da sustentabilidade. Tal modelo foi desenvolvido com a abordagem de Design Science, tendo sido aplicado em três canteiros de obras da cidade de Fortaleza, CE. Observou-se que o modelo é capaz de sintetizar grande número de variáveis, em termos de possibilidades de ações gerenciais e em termos de resultados sustentáveis – numa avaliação qualitativa. Por outro lado, o modelo também apresenta uma avaliação quantitativa, atribuindo um grau de sustentabilidade a cada canteiro. Diferentemente de grande parte dos modelos disponíveis na literatura, esta proposta considera de maneira flexível e auto avaliativa as ações necessárias para que o canteiro de obras seja tido como sustentável (em função da etapa de construção) versus as ações que estão sendo efetivamente implementadas. Além da análise individual de cada canteiro de obras, o modelo possibilita a avaliação do grau de

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sustentabilidade ao longo das várias etapas de construção e fornece uma perspectiva estruturada para comparar diferentes canteiros de obras de uma mesma empresa e de diferentes empresas, criando condições para a promoção do benchmarking, ao mesmo tempo que respeita o que pode ser exigido e implementado em cada condição específica de um projeto de construção.

Palavras-chave: Sustentabilidade; *Lean*; *Green*; *Well-being*; Modelo de avaliação.

1 Introduction

Construction industry is characterized by a huge consumption of natural resources and its effects on potential environment degradation. In the course of transforming the natural environment into a built environment, many hazardous impacts can be identified throughout the project life cycle (Agopyan & John, 2011; Passuello et al., 2014). At its onset, a sustainable construction site might be a first good step towards an overall better project performance.

A sustainable site would provide a more significant impact on society if the triple bottom line approach is taken, bringing together its economic, environmental and social benefits (Elkington, 1999). Further down, once the building site is handed over, after several construction stages are completed, the triple bottom line approach should be enforced throughout commissioning, operating, refurbishing and finally dismantling the building after its service life (Piccoli et al., 2008).

“There is a general agreement that uncontrolled exploitation of natural resources is not beneficial to humankind in the long term” (Hill & Bowen, 1997, p. 225), what has awakened public opinion to address sustainable development (Pardini, 2009). This gives incentives to private companies to endeavor actions in order to compensate or reduce the impact of their deleterious actions, even without legal obligations to do so (McDermott, 2009).

Notwithstanding, this effort has generally been narrowed down to the application of green concepts to project design, to waste control during construction and to the adherence to public or private codes of practices as the LEED assessment model (Darko & Chan, 2016). A truly systematic triple bottom line effort as proposed by Elkington (1999) aiming at establishing guidelines for a sustainable building industry is still lacking. For example, the social pillar is poorly explored and presents a huge number of knowledge gaps (Wilkinson et al., 2012) because the main studies in connection to this subject are predominantly focused on safety and health issues (Xia et al., 2018).

Thus, this research work takes the view that the application of knowledge derived from individual disciplines like Lean Thinking, Green Building and Quality of Working Life (this latter as a representative set of actions in connection to the triple bottom line social pillar), taken individually or as combinations, are not enough to support a more encompassing view on sustainability. Well-being concepts are brought into light in order to fill this gap.

Following the Design Science approach, the model was applied in three construction sites in the city of Fortaleza, northeast of Brazil. Finally, results are presented to validate the performance evaluation model proposed.

2 Lean, green and well-being: an integrated approach to construction site

The Lean Thinking research community spread its academic reasoning's to different areas like supply management, design management, health and safety, building maintenance and building refurbishment, widening initial concerns restricted to production planning and control. It was a natural step to accommodate the concurrent green concept under its value umbrella. This is equivalent to credit environmental concerns to clients' needs in the previous Quality Movement research thrust. A more careful research methodology would be first to identify similarities between Lean and Green, Lean and Sustainability, Lean and Health & Safety, and Lean and Social Responsibility and then proceed towards the meritorious scientific goal of identifying a common or a leading knowledge discipline.

Ng et al. (2010) related lean and safety using a set of indicators to assess safety performance, demonstrating the positive impacts of a lean environment to the reduction of hazards on site. Following that, Slivon et al. (2010) claimed a deeper human concern in Lean Thinking. Benefits to internal human employees or to external human needs and desires should be taken as the primary end result of managerial efforts and not just as another issue that should be systemically contemplated, whatever its relative importance in a building company strategy.

Chronologically in the following year, papers by Alarcón et al. (2011), Antillón et al. (2011) and Leino & Elfving (2011) elected the positive impacts of Lean Construction to Health & Safety as a testimony of the former wide-ranging effects. On the other hand Salvatierra-Garrido & Pasquire (2011) and Vieira & Cachadinha (2011) contributed to both Lean and Green disciplines with evidences on their conceptual interactions.

Well-being, according to Ryan & Deci (2000) and Sen (1993), encompasses motivational and self-determination, both individual and collective satisfaction, involvement with company's values and shared vision. It derives from anthropological findings on how humans have evolved, but accepting psychological views on how man behaves according to a specific culture. It has been incorporated into managerial techniques through psychologist and sociologists' observations on how man is motivated and reacts while performing work. It might be comprehensively addressed with guidelines derived from the discipline of Quality of Working Life (Walton, 1973) taking a step forward, as it is exemplified in the next paragraph.

For the purposes of this research work, well-being concepts are needed to provide a proper building site, according to what follows. It expands on lean guidance that would organize a site with a rational layout, while green (and sustainability) would minimize the consumption of resources and adequate discharge of their debris. Further to that, the Quality of Working Life discipline would dictate the provision of a legally sound, socially encouraging and individually defying environment. This is not enough according to well-being: a proper site is a place where individuals want to be, feel at ease, and find out the necessary support to develop their selves. This is the kind of atmosphere that is associated with craft work of self-employed artisans, as illustrated by Sennet work (2009, 2012).

Failing to specifically obtain relevant literature on the conceptual interaction of Lean, Green and Well-being, a more encouraging research avenue was found in connection to practical means of integrating different knowledge disciplines, as the recent works of Rosenbaum et al. (2012), Carneiro et al. (2012) and Campos et al. (2012). Most of such studies usually provide a performance assessment model to evaluate managerial maturity while combining sustainability and lean construction aspects.

This practical methodological approach, rather than qualitative or quantitative findings on possible discipline interactions, is found in Valente et al. (2013). They proposed a coherent application of lean and green concepts to a building development at the strategic, tactical and operational level. Salem et al. (2014) analyzed the commanding role of Lean Construction on a triple bottom line approach to sustainability, but social impacts on sustainability are again restricted to Health and Safety issues.

It is clearly necessary to go further in the social perspective, and this is where the well-being concept might provocatively help. For example, cell production promotes employee's empowerment, what can be introduced as one more item in a triple bottom line checklist using the already mentioned Quality of Life at Work concept. Just taken empowerment as another item to be evaluated does not suffice: well-being would go further, expressing the positive feelings related to the possibilities of alternatively using power or accepting a subordinate relationship at work. Moreover, well-being would suggest investigating how much cell production workers feel comfortable performing teamwork, instead of taking for granted that group work is rewarding in itself.

Degani (2003) puts forward a matrix to evaluate environmental actions and their corresponding impacts on a building development. Araújo (2009) employed this matrix to contemplate best practices found in a number of building sites and their possible effects on sustainability. This research work uses both matrix and checklist techniques to address the problem on how to evaluate lean, green and well-being actions on building sites. However, it recognizes that such approach leads to extensive lists of actions and extensive lists of impacts, what becomes even more complex due to the objective of addressing a balanced view on economic, environmental and social aspects. This research work proposes to simplify handling too many variables by narrowing down the number of impacts on the economic, environment and social areas and also the possible enacting managerial actions that would increase performance. This narrowing down approach is based on what site management, on a flexible and guided self-evaluation approach, regard as significant.

3 Research method

3.1 Methodological approach

Design Science (DS) was used as a research strategy. DS creates and evaluates artifacts intended to solve existing organizational problems (Hevner et al., 2004). This approach is eminently focused on solving practical problems instead of analyzing laws of nature or behavioural theories (Collins et al., 2004). Even if the artifact is not entirely sound in theoretical terms, one of the key issues regarding its validity is how it can be put in good use in operational terms. Methodological rigor is obtained through a research process containing seven steps, as suggested by Hevner et al. (2004), as depicted in Figure 1.

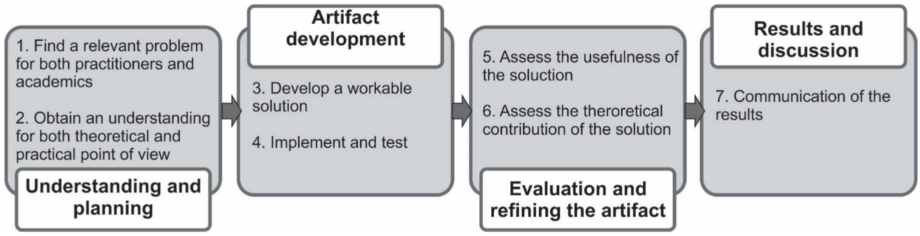

Figure 1. Design Research Process. Source: the authors, based on Hevner et al. (2004).

The DS research strategy was used to create a solution to the following management problem: how to create a method to integrate a list of actions derived from Lean, Green and Well-being with their potential impacts in economic, environmental and social outcomes, leading jointly to a more sustainable building site?

Such administrative tool should take into account that site administrative personnel might freely hypothesize actions and associate impacts. They might choose actions and outcomes according to what is deemed adequate to different stages of progress on a building site and what such management personnel understand as appropriate to obtain sustainable outcomes. Moreover, if site personnel decides to embark in less time-consuming evaluations, or are aiming at a more modest performance, they should feel free to choose a restricted set of actions and impacts.

Thus, such development approach is one of the differentials claimed by this research work as compared to more inflexible evaluation tools. The hazards of construction site are ranked according to their level of impact (low, intermediary or superior) enabling managers to take the most appropriate and potential remedy actions instead of facing a fixed checklist of items produced elsewhere with no consideration of the actual circumstances each project and its production team are dealing with.

3.2 Model for evaluation to sustainability of construction site

The proposed model is characterized by three different parts: 1) Building company characterization; 2) Sustainable profile of the construction site and 3) Checklist of sustainability best practices that might be taken into consideration. In following, each part is detailed. It is worth noticing that engagement of the construction site team and head office personnel is crucial to carry on this proposed methodology.

3.2.1 Building company characterization

This is just a formal procedure to elicit recent developments in the areas of lean production, green building and social awareness the building company is acquainted with, either because it is already experienced in their use or plans to introduce them in new construction sites. It is useful to address if the ongoing building project is to enhance their practice, keep to existing procedures or even step down to a less sophisticated coupling of actions and impacts on sustainability.

This section might contemplate former strategic plans, TQM procedures, compliance to Quality, Environment and Safety certifications and data/ image banks of recent developments with successful implementation of sustainable efforts. It should be pointed out that this section is of tantamount importance for building companies that are starting their efforts towards better sustainability practices: it makes it clear that at these initial stages much should not be expected from them and results should be judged against modest objectives.

3.2.2 Sustainable profile of the construction site

Each construction site is unique and its impact on the triple bottom dimensions is to be analyzed individually. Thus, it is necessary to create a matrix relating possible areas of site management actions and sustainability impacts that are relevant to the circumstances. From now on, those areas of possible management actions will be named Groups of Management Actions, for short Groups of Actions Following Degani (2003) and Araújo (2009), a list of management actions related to lean, green and well-being is produced, taking the form of the vertical axis in a matrix, like the one displayed on Table 1.

The A x I (Aspects x Impact) matrix presents 34 groups of possible managerial actions into 5 categories: management of resources, nuisances and pollution, construction waste, infrastructure of the construction site and social issues.

Within the 34 groups of actions on the vertical axis there is a list of 108 suggested sustainable practices. Such practices were derived from the literature and represent the best available source of ideas on how to deal with sustainability in real applications. For reasons of space such list of 108 practices is not presented in this report. It should be added that such list can be enlarged according to the site production and head office team experience. If so they are added to step 1 - building site characterization – in order to produce documents on their origin. The idea is to experiment with new practices, improve existing ones or to put down inappropriate ones.

Table 1. Matrix of relevant aspects versus environmental impact of construction site (A x I Matrix).

Company: | **Interviewed/ fuction:**

Construction Site: | Type of construction project:

MATRIX OF ENVIRONMENTAL IMPACT OF CONSTRUCTION SITE		Economic, Social and environmental impacts																													CLASSIFICATION			
		Physical environment															Anthropic environment																	
		Soil				Air		Water					Biotic environment				Employee		Neighbourship									Society			B	I	S	
Category	Sustainable aspects	Impact on physical properties	Chemical contamination	Erosion Induction	Mineral resources exhaustion	Decrease in air quality	Noise Pollution	Impacts on surface water quality	Increase of solid quantity	Impacts on groundwater quality	Impact on flow regimes	Water shortage	Impact on local fauna	Impact on local flora	Change in local ecosystems	Change in global ecosystems	Change in health and well-being	Change in safety conditions	Change in landscape	Change in health and welfare conditions	Nuisance to Neighbourhood	Change in local traffic	Pressure over public urban services (except drainage)	Changes in security conditions	Damage to other buildings	Interference in urban drainage	Eletricity shortage	Pressure over public urban services (except drainage)	Increase the volume of waste in landfills	Interference in urban drainage	BASIC	INTERMEDIARY	SUPERIOR	SUSTAINABILITY PROFILE OF CONSTRUCTION SITE
Management of Resources	Consumption of resources (includes built-in loss and packaging)																																	
	Consumption and waste of water																																	
	Consumption and waste of eletricity energy																																	
Nuisances and pollution	Generation of dangerous waste																																	
	Generation of solid waste																																	
	Vibration emission																																	
	Sound emission																																	
	Fragments release																																	
	Emission of particulate matter																																	
	Risk of sparks generation about dispersed gas																																	
	Release of gases, fibers and other																																	

Company:		**Interviewed/ fuction:**
	Air renewal	
	Management of dangerous materials	
Construction waste	Loss of material by discarded wastes	
	Waste management	
	Waste destination (includes discard of renewable resources)	
	Management and destination of dangerous materials	
	Burning waste in construction site	
Infrastructure of construction site	Demolishing	
	Suppression of vegetation	
	Risk of landslides	
	Existence of tentative links (except water supply)	
	Depletion of water supply	
	Risk of perforation of networks of water supply	
	Power generation on construction site	
	Existence of temporary constructions	
	Waterproofing of surfaces	
	Occupation of public streets	
	Material Storage	
	Movement of materials, equipment, machinery and vehicles	
	Maintenance and cleaning of work tools, equipment, machinery and vehicles	
Social Issues	Development of own labor, subcontractors or suppliers	
	Development of Safety and health	
	Local development	

B – Basic; I – Intermediary; S – Superior. Source: the authors.

Table 2 exemplifies how scores are obtained within the matrix format. Just part of the whole matrix is displayed, but results are evaluated as if only such part adds to the scoring system. First, a notation is used to subjectively assess impacts of a line into a row. A circle describes a substantial impact while an X implies that just a simple impact is expected. If nothing is added to a cell it means that no relationship is foreseeable for the pair of line and row variables.

Table 2. Example of matrix of environmental impact of construction site.

MATRIX OF ENVIRONMENTAL IMPACT OF CONSTRUCTION SITE		Economic, Social and environmental impacts																	
		Anthropic environment														CLASSIFICATION			
		Employee		Neighbourship										Society					
																B	I	S	
Category	Sustainable aspects	Change in health and well-being	Change in safety conditions	Change in landscape	Change in health and welfare conditions	Nuisance to Neighbourhood	Change in local traffic	Pressure over public urban services (except drainage)	Changes in security conditions	Damage to other buildings	Interference in urban drainage	Eletricity shortage	Pressure over public urban services (except drainage)	Increase the volume of waste in landfills	Interference in urban drainage	BASIC	INTERMEDIARY	SUPERIOR	SUSTAINABILITY PROFILE OF CONSTRUCTION SITE
Social Issues	Development of own labor, subcontractors or suppliers	O	O		X				X										
	Development of Safety and health	O	O	X	O		X		O										
	Local development		O	X	O	O	X	X	X	X	O								

Legend: B – Basic; I – Intermediary; S – Superior; O - describes a substantial impact is expected; X - a simple impact is expected. Source: the authors.

It is here proposed that a group of management actions represented by a line will have a significant (superior) impact on the array of sustainability variables if the number of circles is greater than the number of Xs (and this scores 3). An intermediate impact is associated with the number of circles equal to the number of Xs (and this scores 2). A basic impact is associated with the number of circles smaller than the number of X (and it scores 1). This scoring scheme is subjective and might be changed by prospective users; care should be taken to maintain the same scoring system when comparing different building sites.

For example, in Table 2, the group of management actions related to the development of own labor, subcontractors or suppliers has the same number of circles and Xs, what indicates that its impacts as intermediate. For Development of Safety and Health 4 circles and 2 Xs are marked, what is taken as a superior impact. Finally, Local Development (fostering local institutions or companies) is associated with 4 circles and 5 Xs and thus this group of actions impact is classified as basic.

All the three groups of management actions exemplified in the preceding paragraph are related to social issues. There are in total 10 circles and 9 Xs for this part of the A x I matrix. If for the whole matrix, not only the 14 columns depicted in Table 2, the number of circles is greater than the number of X, it can be said that social related actions are significant as far as impacting performance in economic, environmental and social dimensions. It should be noted that social actions being graded as superior does not imply that this particular project development is lacking of social actions. It might be that it is a particular case where more than average social concerns would contribute to an improved triple bottom line performance. Or it might be the case that this particular construction site management team is willing to improve its social related abilities, taking as hypotheses that those abilities might positively effect performance in the three bottom line dimensions. That is, management team proposes to increase its social related abilities and would be judged according to that, taking into account the number of management actions they can enact. It should be observed that the proposed methodology does not take into account, for the moment, if such management actions are successful in improving sustainability. They are taken as successful at this stage of the artifact development. This former discussion illustrates how flexible is the methodology being introduced through this present research effort.

3.2.3 Checklist of sustainability best practice

As quoted previously, there is a suggested list of 108 best practices that might be implemented in a construction site to improve its performance: 40 of them are related to lean construction ideas, 42 are connected to green building initiatives and 26 to well-being improvements on human related issues. As there are 34 groups of management actions and 108 best practices, roughly 3 best practices were associated with each of such groups.

These practices area also classified in basic, intermediate and superior regarding their potential impacts on the triple bottom dimensions they are related to. Classification is derived from the literature, taking into account subjective weights previous authors inferred to them. If deemed relevant such classification might be changed. A summary list of such actions and their classification is presented in Table 3. They are presented in full in the original Vasconcelos (2013) Msc. Dissertation.

Table 3. Summary of management actions.

Category	Concerns	Requirements / Number of practices	B	I	S	Total
Resource Management (Lean)	Management of the selection and consumption of resources (except energy and water)	Actions to allow resources management	1	1	1	3
		Actions to allow the construction waste reduction (rationalize to save resources)	9	8	5	22
	Reduction of energy consumption	Actions to allow the reduction of energy consumption	2	2	1	5
	Reduction of water consumption	Actions to allow the reduction of water consumption	3	1	3	7
	Reduction of inconvenients and pollutions	Actions to allow the reduction of inconvenients and pollutions previously identified	0	1	2	3
Management of construction and demolition waste, nuisances and pollution	Management of construction and demolition waste	Planning development of management of construction waste and system implementation	1	1	2	4
		Actions to allow the waste management, removal and disposal	1	2	1	4
Implementation and operation of construction site infrastructure (Green)	Impact reduction on preliminary construction services	Prevention on demolition services	1	1	1	3
		Actions to allow the preservation of remaining flora	1	1	1	3
		Erosions prevention	1	1	1	3
	Reduction of impacts of implementation of infrastructure of production and support of construction site	Temporary buildings characteristics	1	1	1	3
		Sanitation and energy services	1	1	1	3
		Practices for the circulation and maintenance of vehicles, equipment and machinery	2	2	2	6
		Actions to allow the impact reduction of obstruction of public roads and spaces	1	3	1	5
		Environmental practices of storage and handling products	1	1	1	3
	Reduction of interferences in neighborhood	Communication channels to neighbor interaction (claims and actions)	1	1	1	3
		Actions to allow the neighborhood preservation	0	1	1	2
Social Issues of construction site (Well-being)	Support the development of own labor and subcontractors	Actions to allow the development of labor-hand own	3	3	3	9
	Support for local suppliers development	Actions to allow the development of own subcontractor labor	1	2	1	4
		Actions to allow the development of suppliers	1	1	1	3
	Health and safety of workers	Actions to allow the health and safety of workers	2	2	3	7
	Support local development	Actions to allow the local development	0	1	2	3
		Total	**34**	**38**	**36**	**108**

B – Basic; I – Intermediary; S – Superior. Source: the authors.

As the number of well-being related best practices is small comparatively to the other two sources of management actions (lean with 40 initiatives and green building with 42) it is clearly necessary to increase the social research perspective for further developments of this proposed model. In order to address this topic, a deeper review of the literature should include not only classic references on the subject, (Quality of Working Life – Walton (1973), Well-being – Ryan & Deci (2000), Sen (1993), Workmanship – Sennet (2009, 2012), but also to revisit the literature on Corporate Social Performance (see Carroll, 1979; Carroll & Brown, 2018; Clarkson, 1995; Jamali, 2008; Wartick & Cochran, 1985).

Site administrative personnel will go again through Matrix AxI (depicted in Table 1) now evaluating actual impacts of every management action into every column triple bottom line sustainability variable. As before for every group of management action, each individual management action within a group might have a superior, an intermediate or a basic actual impact. Provided a management action impacts a column variable it will act according to its absolute strength (basic, intermediate and superior) as depicted in Table 4, but its relative strength should be calibrated. Absolute strength is supported by literature review, as already mentioned, while relative impact is calculated as follows.

Relative impacts are evaluated according to a GBC accreditation scheme (Silva, 2007) using a Likert scale with 6 points as proposed by Backer (1995) and Siqueira (2008). Impact scores will range from -3 to +2 (that is, going through -3, -2, -1, 0, +1 and +2 values). In order to illustrate this point, suppose a superior management action (score 3) is choosen to be applied on a particular site but it is not envisaged any triple bottom line dimension impact. Its score would be -3, ascertain that this is a misuse of management effort.

On the other hand, a basic management action (score 1) might affect positively a number of dimensions, but the group it belongs to requires a superior impact, as established in the evaluation of the sustainable profile of the construction site (second phase of the methodology). Its relative score will be -2 (1-3), indicating that management did not made a good choice in enacting such management action: as the group it belongs to is required to substantially impact sustainability, a stronger management action should have been chosen.

Just for the sake for making clear the scoring scheme, take again a potential high impacting management action (score 3), but that according to the sustainable profile for this site (second phase of the methodology) belongs to a group of actions for which only basic impacts are required. Its final score will be +2, that is (3-1). That is, this management action is in general powerful, but the performance it delivers is not required with such strength for this site. As a result, its potential impact of +3 is weaken to +2.

Table 4 shows a hypothetical example of some final scores for specific best practices.

Table 4. Example of relative scoring scheme.

Concerns	Practices	Class.[1]	Required	Accomp.[2]	Scores	Sum
Selection of resources	Use of certified wood at the construction site	B			-1	-6
	Use of sustainable criteria of product selection	I			-2	
	Use of sustainable criteria to supplier's selection	S			-3	
Prevention in the demolition services phase	Provides the building projects before the start of the construction services	B		✓	0	3
	Speeches on reduction of unnecessary resource consumption	I		✓	1	
	Displays the resources consumption through visual dashboard at construction site	S		✓	2	

Legend: [1]Classification; [2] Accomplished – to verify the practice required; B – Basic; I – Intermediary; S – Superior. Source: the authors.

Table 4 shows that the group of management actions related to the selection of resources was associated with different triple bottom line performance. Thus, practices of this kind produce high impact and are crucial to achieve sustainable performance. This is highlighted in grey. Despite of its importance, there are no particular management actions enacted on this site. This inadequacy is identified by the -6 score: the sum of -1 (0-1), -2 (0-2) and -3 (0-3) individual scores for non-compliance with basic management action (strength 1), intermediate management action (strength 2) and a superior management action (strength 3) where of them are required.

Now, take the group of actions associated with prevention of green impacts during demolition work, as classified as basic. It means that for this site not too much care should be addressed to collect, select and dispose materials from demolition work. Three management actions are in force within this group, with respectively a basic, an intermediate and a superior impact on sustainability performance. Sum of scores for this group of actions is 3. The first management action (providing the necessary projects to guide demolition work) is in line with the basic requirements for this group of management actions: it scores 0 (1-1).

The second management action is to permanently give guidance to workers on how demolition work can be dealt with taking care of the environment: its score is +1 (2-1), that is, this management action is a little bit more than what is required for these site circumstances.

Finally, providing visual information on how demolition materials are accumulating on site scores +2 (3-1). It is a strong practice, as identified in the literature, but again, its impact is much more stronger that it is required according to management judgment related do the sustainable profile of the construction site (phase 2).

After examining a maximum of 108 management actions impacts on sustainability, results are displayed in orthogonal axis. Abscissa values (x axis) represent how much sustainable this particular building site should be. This is done by comparing lean, green and well-being disciplines (as represented by lines in the A x I matrix) to their influence on outcomes as related to economic, environmental and social performance.

As already mentioned, this score is obtained by comparing lines and columns in matrix A x I. It should be remembered that is up to site management decide what do expect as sustainable performance and on how each line in the matrix Ax I is planned to impact sustainability outcomes. Thus, it might be that abscissa values are small, if small sustainability outcomes are planned (or expected) for this site. Each line in matrix A x I will be associated with a basic, intermediate or superior relationship between lines and the set of all column's variables. As there are 34 lines to be evaluated at the second phase of this methodology, and basic, intermediate and superior relationships are associated with 1, 2 and 3, maximum score is 34 x 3 = 102.

Minimum score is zero, that is, even acknowledging that groups of management action influence columns sustainability outcomes, site management might not be planning to empower their acting. It is obviously an extreme situation, where project outcomes in economic, environmental and social terms would be absolutely circumstantial, not based on any deliberate management effort in the areas of lean, green and well-being. Abscissa values are standardized in the interval 0-100. interval.

On the other hand, ordinate (y axis) values represent how much management actions might impact sustainability. Its results are taken as the sum of all scores for possible management actions identified in the checklist of sustainable best practices (third part of this methodology). Minimum sum of scores is -218 and maximum is +110. The minimum score is obtained when the second phase of the methodology indicates only empty cells for the whole A x I matrix. This is an extreme case, where no impact is required from groups of management actions on triple bottom line sustainability performance variables.

Out of the 108 suggested management actions, 34 of them are basic and thus would impact 34 x (0-1) = -34; 38 are intermediate and thus would impact 38 x (0-2) = -76; 36 are superior and thus would impact 36 x (0-3) = -108. The sum is -218 and means that there is a relative wastage of management effort, as 218 scores for better performance are in force, but none is required according to site management decisions.

Maximum sum of scores is obtained when all 34 groups of actions indicate basic impacts on the sustainability performance variables according to the second phase of the methodology. The whole range of 108 management actions are in use, impacting 34 x (1-1) = 0 in connection to the 34 basic management actions, 38 x (2-1) = 38 in connection to the intermediate management actions and 36 x (3-1) = 72 in connection to the superior management actions. The sum is 110 and it means that there is a surplus of management effort. More is enacted then required.

Both extreme situations are not expected to occur. If management effort is to be deployed, selecting management actions that might deliver a positive impact on sustainability performance, it is expected that site management will be coherent while performing phase 2 and 3 of this methodology: if much is required much should be enacted, if less is required not much management effort should be deployed.

A standardization procedure is applied to the Y axis (-218 is taken as 0 and +110 is taken as 100. Standardized scales allow the comparison and benchmarking of different construction sites and also different phases of construction within a particular site, each of them with their particular sustainable management practices and corresponding impacts.

Both axis, sustainability profile (x axis) and sustainability achievements (y axis) are dependent on management decisions on what level of performance is deemed adequate and how to achieve them through lean, green and well-being actions.

4 Results and discussion

4.1 Construction Site A

This building project corresponds to an apartment development with one tower with 11 floors, basement floor and ground floor. There is a total of 88 apartments summing a gross area of 2.677,40 m^2. The sustainability exercise was applied during the initial stages of construction, while the building foundations were being prepared. One of the major problems was the constant use of pumping devices to dry the underground area while foundation work was in progress (Figure 2). This was of special concern as it will impact on urban drainage, cleanliness and mobility in the adjacent neighborough area, as water was being pumped onto the streets (Figure 3).

Figure 2. Drawdown of level of water on the ground. Source: the authors.

Figure 3. Dumping water in urban drainage network. Source: the authors.

The sustainability profile and scores standardized to each category are presented in Table 5, taking into account the first two steps in the methodology under development in this Design Science Research undertaken.

Table 5. Sustainability profile and scores standardized for Construction Site A.

Dimension	Category	Sustainability Profile	Score Standardized	
			Required	Achieved
Lean	Management of Resources	Superior	100.00	77.22
Green	Nuisances and pollution	Superior	100.00	100.00
	Construction waste	Superior	100.00	73.33
	Infrastructure of construction site	Basic	24.00	89.13
Well-being	Social Issues	Intermediary	71.43	68.57
		General	**75.27**	**79.12**

Source: the authors.

The results are graphically displayed in Figure 4 and Figure 5. Radar charts are also introduced in order to help site personnel to depict weaknesses and strengths of its sustainability management system at a glance. Moreover, they call attention to the lack of balance between what was planned and actually potentially achieved.

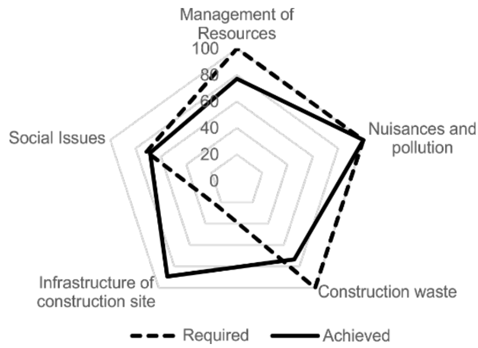

Figure 4. Scores by category: required x achieved (Construction Site A). Source: the authors.

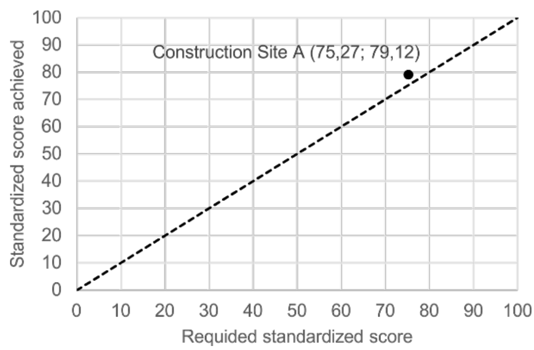

Figure 5. Required score x score achieved (Construction Site A). Source: the authors.

Just for the sake of illustration, among the 108 possible management actions, only a few were selected by site managers to enact lean, green and well-being disciplines, regarding their impacts on economic, environmental and social dimensions. Lean practices were represented by the use of a Kanban's system and Heijunka-box to balance flow improvements with conversion improvements. Green concerns were contemplated by the use of a duct for waste transport upstairs down to collecting bins. Well-being actions are represented by the use of paved sidewalks, fences and correct traffic signaling to help passers by circulate outside the site under construction. In addition to that, leisure and amusement activities were provided for site workers, like music presentations and a billiard table. (Figures 6 and 7).

Figure 6. Music show . Source: the authors.

Figure 7. Billiard table. Source: the authors.

4.2 Construction Site B

Site B is a housing project with 5 towers with 7 floors each. There is a total of 208 apartments with 17361,95 m^2. Sustainability evaluation was performed during the structural masonry elevation phase. The land plot is situated in an undrained part of the city, with potential contamination of the soil and hazards for the nearby flora and fauna of an undeveloped rural area in the vicinity. This site is characterized by special concerns related to the biotic and physical environment (Figures 8 and 9)

Figure 8. Impact on local flora. Source: the authors.

Figure 9. Construction tower view. Source: the authors.

The sustainability profile and standardized scores are presented in Table 6.

Table 6. Sustainability profile and scores standardized for Construction Site B.

Dimension	Category	Sustainability Profile	Score Standardized	
			Required	Achieved
Lean	Management of Resources	Superior	81.00	60.00
Green	Nuisances and pollution	Superior	100.00	86.00
	Construction waste	Superior	100.00	53.00
	Infrastructure of construction site	Basic	24.00	67.00
Well-being	Social Issues	Intermediary	71.00	66.00
		General	**65.00**	**64.00**

Source: the authors.

The results are graphical displayed in Figure 10 and Figure 11.

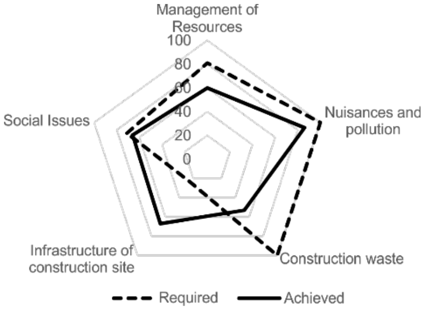

Figure 10. Scores by category: required x achieved (Construction Site B). Source: the authors.

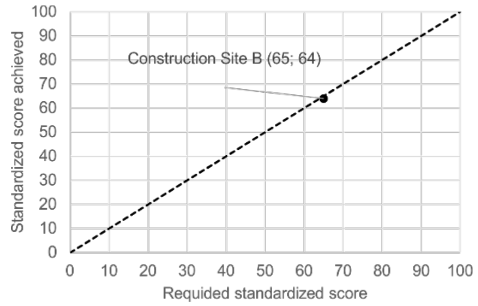

Figure 11. Required score x score achieved (Construction Site B). Source: the authors.

Lean practices are related to the use of a Kanban system for materials delivery for each work station and cell production (Figure 12). Site layout, paved sidewalks and clear pathways in and out the building site helps to improve the connections between construction works and the surrounding area (Figure 13), what makes it easier for workers, visitors and suppliers to access the site.

Figure 12. Cell production. Source: the authors.

Figure 13. Protected sidewalks and access to the site. Source: the authors.

Well-being is potentially fostered by artistic presentations on site carried on by the children of workers on special occasions (Figure 14) and foremen training in CAD (Figure 15).

Figure 14. Artistic performances. Source: the authors.

Figure 15. Foreman's training. Source: the authors.

4.3 Construction Site C

Building Project C is a housing project with two towers comprising 22 floors with apartments, garage basement, ground floor and a mezzanine. There are 107 apartments with a total area of 5.360,00 m^2. A traditional reinforced concrete structure is used. Sustainability evaluation was carried on during the final stages of construction, with façade and internal finishings as the more demanding jobs at this particular time in the construction schedule (Figures 16 and 17).

Figure 16. Façade execution. Source: the authors.

Figure 17. Interior finishes. Source: the authors.

This site is situated in a completely urbanized part of the city, with urban drainage and sanitation. Garage basement is below the urban drainage and sanitation city network. Residual debris and water might run to the basement and contaminate the urban drainage system when they are pumped away. Apart from that, failing to provide proper basement drainage causes dampness and rising underground water levels in underground floors.

The sustainability profile and standardized scores for each category are presented in Table 7.

Table 7. Sustainability profile and scores standardized for Construction Site C.

Dimension	Category	Sustainability Profile	Score Standardized	
			Required	Achieved
Lean	Management of Resources	Superior	100.00	42.00
Green	Nuisances and pollution	Superior	100.00	43.00
	Construction waste	Superior	100.00	40.00
	Infrastructure of construction site	Basic	24.00	46.00
Well-being	Social Issues	Intermediary	71.00	57.00
		General	**75.00**	**46.00**

Source: the authors.

The results are graphical displayed in Figure 18 and Figure 19.

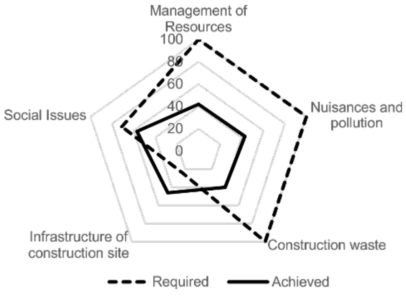

Figure 18. Scores by category: required x achieved (Construction Site C). Source: the authors.

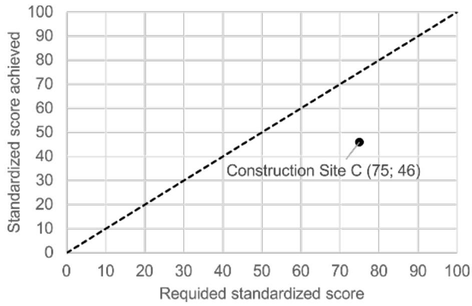

Figure 19. Required score x score achieved (Construction Site C). Source: the authors.

There are no sustainable practices identified in construction site C apart from the ones related to health and safety that are mandatory according to Brazilian law. Thus, sustainability performance is achieved only in connection to these legal requirements. Even so, the project was poorly managed and Figure 20 exemplifies the lack of concern with workers safety.

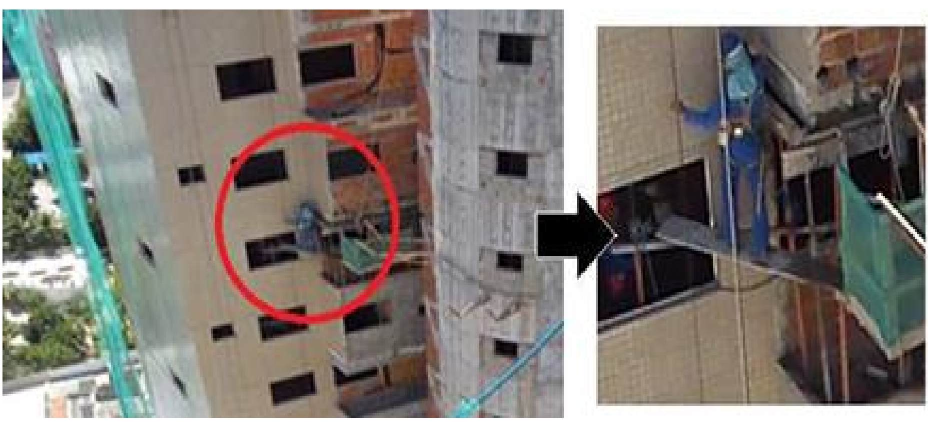

Figure 20. Unsafe construction site example. Source: the authors.

4.4 Comparative analysis

Figure 21 plots global scores for sites A, B and C.

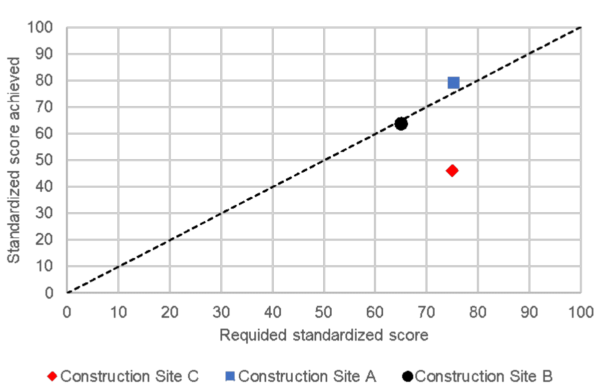

Figure 21. Comparative Analysis of standardized score achieved. Source: the authors.

Site A has a minimum required standardized score of 75 and it is able to achieve an actual standardized score of 79. It means that site management plans to impact only 75% of all sustainability outcomes he has chosen as adequate in phase 2 (sustainable profile of the building site). A quarter of the group of actions (25%) will be neglected, because corresponding management actions for that set of groups will not be enacted in phase 3 (checklist of sustainability best practices). Notwithstanding, the selected group of management actions within each group might perform slightly better than required (79 vs 75).

Both figures represent what is planned and potentially achieved for this site and its characteristics, in terms of sustainability requirements and management actions that are on course.no Alternatively, they might represent management actions and sustainability requirements this site is committed to address at this moment in time. This second option is an interesting methodological characteristic of the proposed evaluation artifact: no a priori requirements are in force: standards are set by its own managerial staff, instead of following a checklist that is externally imposed.

Site A might rearrange its scores in order plan and achieve 100% of its sustantabilty performance: it is just a matter of selecting a group of actions and corresponding management actions to fit such requirements and outcomes. This playing with numbers exercise will prevent management staff to face defying objectives. On the other hand, it might promote the use of management actions just fit for the purpose, preventing their more than required capacity to improve even better sustainability performance.

Site B commits itself to pursue a set of management actions that would theoretically impact 65% of the sustainability requirements set in Table 2. In actual terms, this site was able to achieve 64% of the sustainability requirements, just under the figure it is committed to. Note that in actual terms, for example, it might be that this site is getting better than committed impacts due to lean actions, and worse than committed for the other two areas: notwithstanding differences between planned and actual performance for lean, green and well-being areas, the site is delivering sustainability as planned.

Site C is not sustainable according to its own standards. Its management staff commits itself to affect positively 75% of all sustainability requirements in Table 1 but it is able to achieve only 46% of them. This score is achieved merely using management actions related to legal requirements on safety and health.

Figures 22 and 23 present a comparative analysis for the three different sites under investigation.

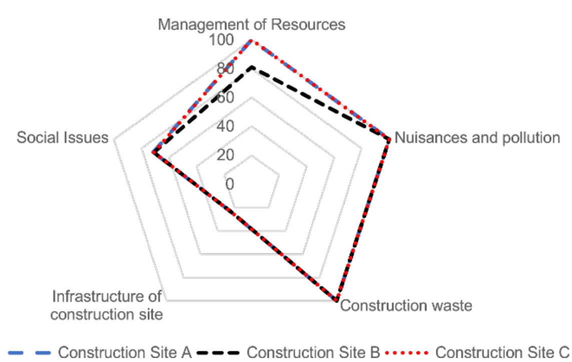

Figure 22. Comparative analysis of the required scores by category. Source: the authors.

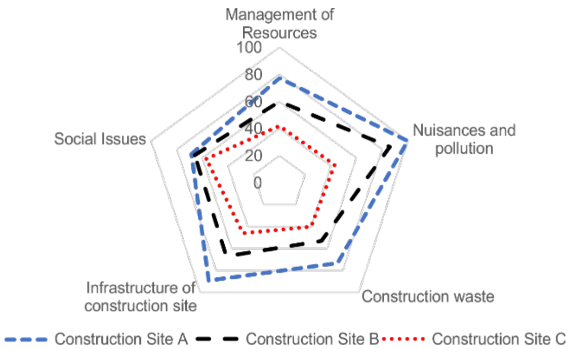

Figure 23. Comparative analysis of the achieved scores by category. Source: the authors.

Figure 22 ascertain that the three sites were managed under the same planned sustainability performance to be achieved, regarding management of resources, nuisances and pollution, construction waste, infrastructure of the construction site and social issues. Those five different areas represent a first expansion of lean (management of resources), green (nuisances/ pollution and construction waste) and well-being (infrastructure of the construction site and social issues) group of action categories. This means that, in quantitative terms, actions planned for each construction site produce similar impacts on sustainable performance. Notwithstanding, the qualitative analysis carried out highlight differences in terms of areas of concerns associated with each site.

This is what might be expected: sites are located in different parts of the urban network and were analyzed in quite different stages of work. Notwithstanding construction culture might be taken as similar in the city of Fortaleza, as building companies and managerial staff are acquainted with similar practices and might give similar weights to what is important in terms of sustainability performance.

It is also worth noting in figure 22 the low minimum score required for the infrastructure of construction site category. For the three different sites it scored 24 and is classified as basic by the different site management staff. It might be that this reflects again a building culture in the city of Fortaleza. Due to widespread use of Total Quality and Lean Construction Programs most construction companies did improve their sites in terms of workers accommodation, leisure activities, food and rest facilities: thus, actions related to these areas are not taken any more as capable of promoting still better degrees of sustainability. They are now taken for granted, as an obligation.

Figure 23 deals with achieved sustainability. Site A consistently performs better than the others. For the three different sites, actions related to the control of nuisances and pollution are the major contributors for sustainability performance, regardless of the general performance level each site is likely to achieve using the chosen management actions. Site C scores the worst, but consistently draws scarce improvements from the five different areas that are summarizing lean, green and well-being actions. Mandatory regulations imply the use of management actions taken from the five different areas, but all of them contribute meagerly.

Finally, the comparative radar charts call attention to the lack of balance between what was planned and actually achieved. For project A, infrastructure of the construction performed better than it was initially planned for. As already explained, no hopes are deposited on them as sponsors of better performance, but as they are actually in force in every site in Fortaleza they help naturally achieving such better outcome.

For Project B, site infrastructure and control of building waste have different scores as related to favoring and actually achieving better performance. Explanations for such disagreement are as follows: for site infrastructure, the same explanation for Site A holds; control of building waste should be empowered and better managed, using a more comprehensive set of management tools to achieve what is planned for this green area of expertise

Site C shows a less than expected actual contribution to performance than initially envisaged, apart the aforementioned analyses for the site infrastructure well-being category. As it was a site poorly managed, all different areas of possible improvement in sustainability performance were neglected due to the scarce use of the 108 possible management actions

It might be said that both projects A and project B performed well as related to what they are committed to achieve. This methodological evaluation artifact, on the other hand, made it clear that Site C put higher planned standards for its managerial behavior at the stage of work under analysis (façade and internal finishings) but is not able or did not want to work seriously towards its commitments.

For site A and B, different scores for the five categories being displayed in the radar charts illustrate that different actions in lean, green and well-being might balance their achievements, leading each site to achieve a satisfactory sustainability performance.

5 Conclusion

This research work demonstrated the construction of a new artifact to evaluate sustainability on construction sites, following the triple bottom line approach. Suggestions were made to incorporate lean management actions into the economic triple bottom line pillar; management actions leading to a green site were naturally associated with the environmental pillar, while a new concept, well-being, was introduced to expand the social pillar. Moreover, the integration between them was analyzed and applied in three construction sites to demonstrate its feasibility.

A matrix of relevant management actions versus sustainability impacts on a construction site (A x I Matrix) is proposed following Degani (2003) and Araújo (2009) and constitute a contribution of this work. From the A x I Matrix a sustainable profile can be depicted considering the different stages of progress on a building. Moreover, the same matrix is used, now in and expanded format, incorporating 108 possible lean, green and well-being managerial actions in order to provide hints on their positive relationship with sustainability performance.

A Design Science Research methodological approach provided the background to build a matrix like kind of tool linking actions and outcomes. This made it simple to put together an overwhelming number of possible site management actions and their impacts on sustainability requirements. A synthetic view allows one to evaluate the degree of sustainability a site is able to achieve according to what site management commits itself to achieve. This perspective of judging performance according to commitments, weaker or stronger as they might be, is deemed appropriate to help introduce such evaluations on site, without the imposing requirements of external control, whereby standards are set by actors that are not responsible for the daily site operations.

A suggested scoring scheme induces management to select a balanced set of management actions. It also simplifies the problem of attributing scores for pairs of actions and impacts using cardinal scales. Such cardinal scoring might suffer the same criticism in connection to the lack of scientific rigor, as it might be blamed to this research work artifact.

To conclude, the proposed model contributes to better construction sites, suggesting a balanced view on the use of two ongoing management approaches, lean and green, introducing a third one, well-being. The latter might prove in further research to be an encompassing performance criterion to evaluate the actual final purpose of every construction activity, both for its clients and building operatives.

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