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A systems engineering approach for realizing sustainability in infrastructure projects

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Abstract Sustainability is very quickly becoming a fundamental requirement of the construction industry as it delivers its projects; whether buildings or infrastructures. Throughout more than two decades, a plethora of modeling schemes, evaluation tools and rating systems have been introduced en route to realizing sustainable construction. Many of these, however, lack consensus on evaluation criteria, a robust scientific model that captures the logic behind their sustainability performance evaluation, and therefore experience discrepancies between rated results and actual performance. Moreover, very few of the evaluation tools available satisfactorily address infrastructure projects.

This paper introduces a systems model that abstracts the environment, the construction product, and its production system as three interacting systems that basically exchange materials, energy and information. The model utilizes this setup to capture and quantify essential flows exchanged between such three systems, with the objective of evaluating sustainability. The paper walks through the development of a generic case of the model, and then demonstrates its utility in evaluating the sustainability performance of civil infrastructure projects using a typical water pipeline installation project that uses horizontal directional drilling (HDD) technology as a trenchless installation method.

The developed model addresses an identified gap within the current body of knowledge by considering infrastructure projects. Through the ability to simulate different scenarios, the model enables identifying which activities, products, and processes impact the environment more, and hence potential areas for optimization and improvement.

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Introduction

The construction industry has been identified to be responsible for: (1) more than 30% of energy consumption in Organization for Economic Cooperation and Development (OECD) countries, including the United States, the European Union, Japan, and others, (2) 16% of freshwater withdrawals in the United States and about 20% worldwide, and (3) about 33% of global greenhouse gas emissions, just to name a few [1]. These environmental loadings and impacts have put great pressure on the construction industry to shift from *traditional* to *sustainable construction*. Accordingly, a body of knowledge related to this area has begun to shape and gain momentum during the last two decades [2]. Nevertheless, in spite of the recognized importance and the efforts exerted, sustainable construction is not yet a standard practice of the industry. For example, recent statistics estimate the total number of buildings that were certified according to either the ''Leadership in Energy and Environmental Design'' (LEED) certification program or the ''Building Research Establishment Environmental Assessment Methodology'' (BREEAM) – being the most famous sustainable building rating systems – at less than 1% of buildings worldwide [3]. A number of published research works identify a long list of technical and non-technical barriers to sustainable construction implementation as a standard practice of the industry, including Häkkinen and Belloni [4], Matar et al. [5], Williams and Dair [6], Blair and Evans [7] and Landman [8] among many others. The list of identified barriers is truly long, but literature review reveals that the following barriers are among the most commonly agreed upon and identified ones:

1. The higher initial cost and slow return on investment of sustainable buildings.
2. The lack of training, education, and enough interest from major industry stakeholders.
3. The ambiguity of sustainable construction practices to the wide base of industry practitioners, especially when contrasted to the clear defined codes and standards available for most of the common construction disciplines and activities.
4. The current characteristic fragmentation of construction industry entities preventing or significantly slowing down the effective sharing and dissemination of knowledge.
5. The clatter, confusion and inefficiencies of current tools and approaches to sustainable construction.

The last barrier in particular deserves further elaboration. Logically, with the increasing alertness for the importance of realizing sustainable construction, a huge number of tools and approaches to sustainable construction have been developed. More than 600 sustainability assessment, evaluation and rating systems have been developed worldwide, with evaluation criteria that range from 5 to over 170 [5,9]. Both the large number of assessment tools and the lack of consensus on evaluation criteria are potentially alarming. Furthermore, wide discrepancies between assessment results during the planning and design phases, and the actual performance during real life operation have been found. While energy performance is very often cited as the most important sustainability indicator, it was found to be the least realized [9,10].

Several reasons contribute to this situation of underperformance of sustainability assessment tools, including that they were developed – in many cases – reactively in response to appearing environmental pressures, using reductionism approaches that typically handled single aspects of the problem [2,11,12]. To recognize environmental impacts and unsustainable behaviors, however, there has to be a *holistic model* that correctly captures the complete construction process and its products and how they interact with the environment, something that is usually missing from the current set of tools.

Finally, it is very notable that most of the available sustainability assessment tools address buildings, while very few of them address civil infrastructure projects [3]. Compared to regular buildings, civil infrastructure projects require much greater amounts of difficult planning, financial investments, engineering efforts, and resources of different natures. Moreover, their sustainability impacts span wider areas for potentially longer times. The need to assess the sustainability of civil infrastructure projects is simply crucial.

This paper utilizes a holistic systems approach to develop a systems model that shall permit identification, understanding and evaluation of sustainability parameters and impacts related to civil infrastructure projects. The model represents the following: (1) the environmental system, (2) the infrastructure system (the product), and (3) the infrastructure delivery system (the production system) as three interacting systems that basically exchange (1) energy, (2) matter, and in some cases (3) information, according to systems theory. The Systems Modeling Language (SysML) is utilized to depict the systems; highlighting various system components, key activities, and the flow of resources during the execution of these activities. The model is built along the principles of systems engineering and is demonstrated for a typical pipeline project installed using horizontal directional drilling.

Current approaches to sustainable construction

During the last three decades, while sustainable construction gradually came into focus and attention of different academic and practicing entities and institutions of the industry, a large number of tools that tackle the issue of realizing sustainability in the construction sector have been introduced. Distinguishing and categorizing these numerous types of tools and systems has become increasingly difficult as they have evolved into a myriad of forms. This section focuses principally on sustainable construction and green rating systems, in distinction from tools related to energy simulation, performance evaluation, indoor environmental quality assessments, and operation and maintenance optimization, among many other unrelated but often bundled together as ''sustainable construction and green ratin g/evaluation/assessment'' tools. This brief overview shall concisely look at tools for both buildings and infrastructure.

Sustainability evaluation tools that address buildings

The US General Services Administration (GSA) has twice sponsored an extensive study, with results published in 2006 and 2012, to select and certify tools for its own use for evaluating and certifying federal government buildings. That extensive study has counted and evaluated more than 150 building performance and sustainability evaluation tools. At the first