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There is a Need for Civil Systems Engineering in the Era of the Fourth Industrial Revolution

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Abstract

Civil engineering is a disciplinary discipline. Civil engineers are designing, building and operating systems which need systems approaches and systems engineering methodologies for effective and optimal designing and operating practices. The systems in the fourth industrial revolution are including innovative technologies and smarts subsystems and components. Such a systems poses challenges and opportunities for the civil engineering discipline. It is proposed that the modern civil engineering discipline will adapt and integrate practices and methodologies of advanced systems engineering which fits the needs and challenges of the fourth industrial revolution era.

Keywords: Civil systems engineering; Operating systems; Industrial revolution; Innovative technologies

Introduction

For many decades, each of the industries and domains that relied heavily on engineering such as electronics, mechanics, software, chemistry, and civil, had its own discipline. The engineers of each discipline evolved and gained experience in their respective specialization. But, in the early 1970s, the need arose to integrate the various engineering fields and even to bridge the gap between engineering, as a whole, and nonengineering systems. This phenomenon has its source in two opposing trends: on one hand, engineering disciplines were becoming more and more specialized; and on the other hand, the need for multidisciplinary and interdisciplinary skills and methodologies are on the rise. The last trend is one of the sources for developing the discipline of systems engineering.

Systems Engineering is a dynamic discipline that changes and evolves constantly, adapting to changes in its working environment. It affected by factors like technological change, developments of interfaced disciplines, research findings, and the lessons learned from experience in the industries and in the businesses, to name only few [1]. During the last decade, industries in advanced economies have experienced significant changes in engineering and manufacturing practices, processes, and technologies that have the potential to create a resurgence in their engineering and manufacturing activities. This phenomenon is often referred to as the Fourth Industrial Revolution or Industry 4.0, and is based on advanced manufacturing and engineering technologies, such as massive digitization, big data analytics, advanced robotics and adaptive automation, additive and precisions manufacturing (e.g., 3-D printing), modelling & simulation, artificial intelligence, and the Nano-engineering of materials. Systems engineering experts and practitioners address these innovations and changes from a Systems Engineering perspective, and present Advanced Systems Engineering [2]. Rather than being based in scientific principles, Advanced Systems Engineering consists of a rich and useful set of principles, processes, practices and lessons learned.

Systems engineering is widely practiced in defense, aerospace and communication industries and projects. It is less applied in automotive industries, and it is rarely practiced in construction, infrastructure and civil engineering industries or projects. The practitioners of civil engineering projects claim that the practices of traditional system engineering do not fit the civil engineering ecosystem. There are several reports on applying systems engineering in the civil engineering projects where top management support for systems engineering was established [3]. There are also ongoing efforts of the INCOSE (International Council on Systems engineering-www.incose.org) Infrastructure Working Group to explore how to use systems engineering in civil engineering.

The Challenges for Civil Engineering and their Response

This paper presents the opportunities for applying advanced systems engineering practices and methodologies in civil engineering projects and industries based on the innovations of

the fourth industrial revolution and the use Building Information Modelling (BIM) which transforms through digitization the civil engineering environment [4]. Digitizing building information is reshaping the relationships that users have with the built environment, as well as the roles and responsibilities of the professionals who manage, plan, design, operate, built, deliver and maintain buildings, infrastructures and cities. The capabilities of advanced systems engineering as presented and demonstrated in [1] are synergetic and complementary with the BIM abilities and practices. The below table includes the special capabilities, features and methodologies of advanced systems engineering, compared with those of the traditional systems engineering. It is claimed that these special capabilities are synergetic and complementary with civil engineering life cycle especially when the BIM methodologies are practiced, like:

a) Iterative & agile processes for managing the building and construction through the whole life cycle

b) Using systems modelling (like Model Based Systems Engineering-MBSE) and simulation methodologies as complementary BIM practices

c) Requirements evolution and change management

d) Data driven & Evidence based Systems Engineering

e) Risk management based on evidences, data and models

f) Introducing Innovation and entrepreneurship into the construction ecosystem

g) Human Systems Integration as a developed, advanced and meaningful discipline

h) A system approach for safety of the construction systems and the whole building processes through its whole life cycle

i) Applied and advanced systems thinking

j) Predictive maintenance policy for the infrastructure systems by Conditioned Based Maintenance (CBM) or Prognosis Health Monitoring (PHM) methodologies and practices

k) Proactive Design for Sustainability

l) Enhanced integration of ethical aspects, like private rights, transparency in the civil engineering companies and projects, and in the civil communities who are affected by these projects

m) Working with Startups as sources for innovative ideas and technologies

Table 1: Advanced vs. Traditional Systems Engineering.

Traditional Systems Engineering	Advanced Systems Engineering
Waterfall Model	Iterative & Agile Models
V Model, T&E Scheme	Modeling & Simulations
The boundaries of the system are well defined	The boundaries of the system are vague, porous & changing
Strict Requirements Management	Requirements are changing as an opportunity
Risk Management based on qualitative assessments	Risk Management based on evidences, data & models
Conservative approaches & avoiding changes	Innovation & entrepreneurship as a culture
Rare integration of Human Factors Engineering	Human Systems Integration as a developed, advanced & Meaningful Discipline
Limited integration with Reliability Engineering & RAMS	An integrated approach of RAMS in SE
A process approach for Safety	A System approach for Safety- STAMP
Procedural protection & filters for external threats	System protection for Cyber threats (by STAMP)
Limited System Thinking	Applied & advanced Systems Thinking
Preventive Maintenance Policy	Predictive Maintenance Policy- CBM, PHM
Passive design for environmental issues	Proactive Design for Sustainability
Limited integration of Ethical aspects	Enhanced integration of ethical aspects, like: private rights, transparency
SE based on procedures and processes	MBSE- Model Based Systems Engineering
Internal development and internal demonstration	Using demonstrated elements in the internet and
	in the virtual market Like GITHUB
Working with established companies	Working with Startups
The business aspects are not part of SE	The Business Model is essential part of SE
SE is based on documents	Data driven & Evidence based SE

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n) The Business Model as an essential part of systems engineering and civil engineering (Table 1)

Conclusions

The opportunities and challenges of integration between civil engineering and advanced systems engineering in the era of the fourth industrial revolution is presented. It is claimed that there are substantial benefits of this integration for designing, deploying, maintaining and operating complex civil engineering systems. It is also an opportunity for educating the civil engineers for the 21st century as civil smart system engineer, and it also poses the challenges for the research on the systems aspects of civil engineering. It is proposed to learn the lessons from the aerospace engineering discipline about developing the systems engineering discipline which was founded in this domain.

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