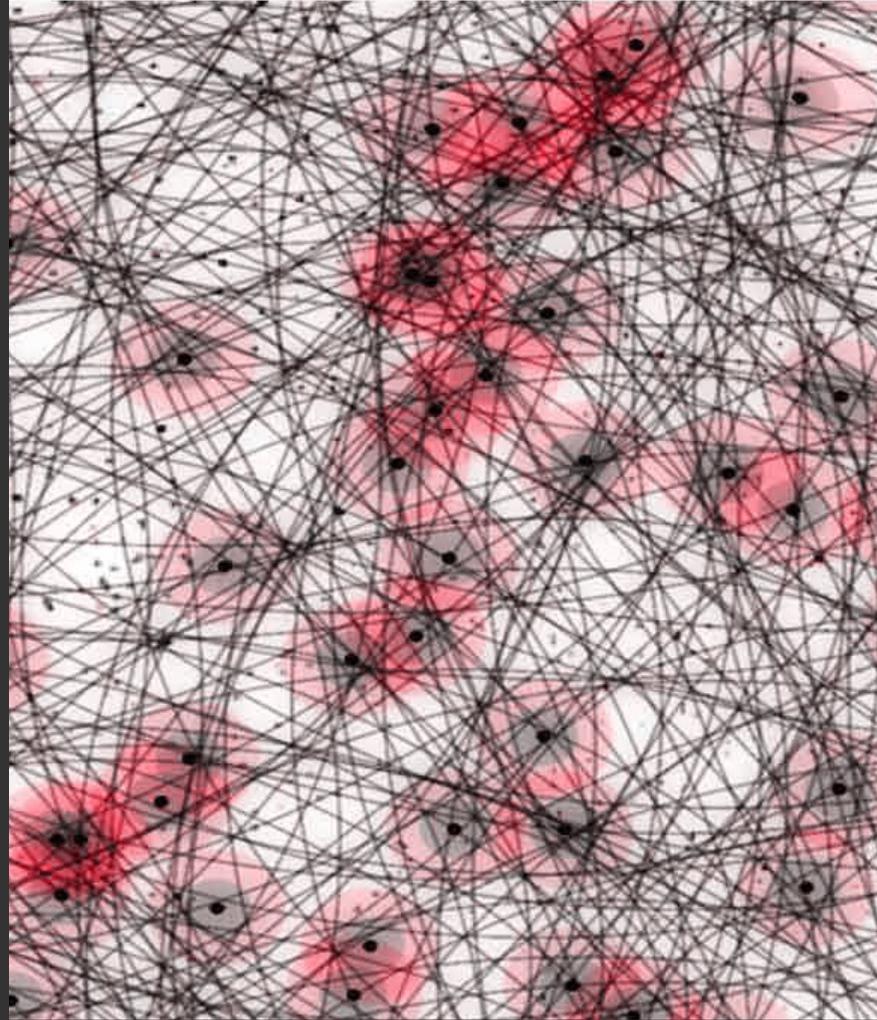


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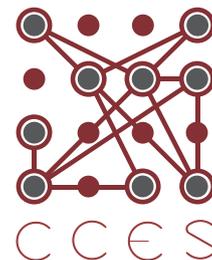
Cover image modified from "Celestial Mechanics" <http://cmlab.com>



Center for Complex Engineering Systems  
at KACST and MIT



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<http://www.cces-kacst-mit.org/>



## Background

We rely heavily on man-made systems such as air and rail transportation, power and water distribution networks, and civic infrastructure of all sorts to meet our daily needs. As the world's population continues to grow and resources come under increasing strain, such systems are becoming increasingly complex and interlinked in unforeseen ways.

This challenge is particularly acute in Saudi Arabia, which is experiencing rapid population growth and a gradual transformation from a petroleum-based to a more knowledge-driven economy in the context of a challenging natural environment requiring optimal resource management.

Complex systems, however, are not defined by the aforementioned physical components alone, but rather by complex, intertwined engineering systems that integrate people, technology, and services. The random, chaotic interaction among such heterogeneous components of the system give way to so-called emergent properties over time--observable phenomena that cannot be ascribed fully to one of the individual components. The Center for Complex Engineering Systems (CCES) at KACST and MIT was created to improve our understanding of complex systems and to jointly conduct world-class research. This requires an unprecedented level of inter-disciplinary collaboration among scientists who study nature, technology and social phenomena at multiple scales.

## CCES Vision

The Center for Complex Engineering Systems (CCES) is a world-class international research program that seeks to uncover fundamental principles and develop new methods in order for such systems to be modeled, designed, and managed more effectively than is currently possible.

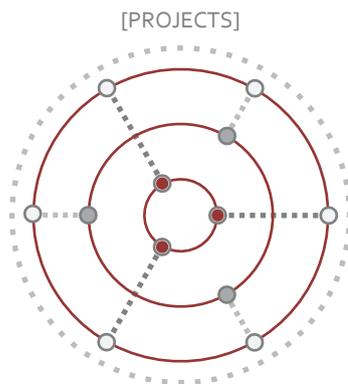
## CCES Mission and Goals

- To help position Saudi Arabia as a new leader in systems thinking and to assist in tackling society's challenges domestically and regionally.
- To excite and inspire a young generation of researchers and engineers in pursuing engineering systems as a research direction.
- To solve previously intractable engineering systems problems by integrating approaches based on engineering, management, and the social sciences using new framing and modeling methodologies.
- To facilitate the beneficial application of engineering systems principles and properties, while ensuring that these solutions are sustainable in terms of social equity, economic development, and environmental impact.
- To value and embrace intellectual risk. This means tackling issues that appear, at least in part, to be non-quantifiable, vague, overly complex or even unsolvable.

## CCES Projects

The problems in complex engineering systems are extraordinarily challenging, broad and interconnected. It would be tempting to simply capitulate in view of these challenges and try to improve the situation by developing individual technologies and inventions. However, the philosophy of CCES is to take a holistic systems view. On the other hand, it is necessary to provide clear focus and direction to achieve research success and advance the state of the art. Defining specific projects provides this focus. Due to the inherent synergy among research topics, a certain amount of the research will be devoted to cross-cutting research in complex engineering systems design, across the requisite ranges of geographic scope, time steps and duration, and degree of resolution.

The CCES research projects are designed not only to achieve excellence in the development and application of the different systems tools and methodologies, but to create metrics, and methods of communication, such that the end product of the research project can be put to use by decision makers and other important actors in Saudi Arabia and beyond.



## What are Complex Engineering Systems (CES)?

Recent advances in science and technology coupled with explosive population growth in some regions have led to a rapid increase in the complexity of most engineering systems. A new class of Complex Engineering Systems (CES) has emerged as a result. This class of systems is characterized by a high degree of technical complexity, social intricacy and elaborate processes that fulfill important functions in society. Such systems include transportation networks, electrical grids, food production and water management systems, defense systems as well as manufacturing supply chains to name a few. Understanding and mastering these large and complicated systems requires a new scientific approach that is focused not simply on the in-depth understanding and optimization of a single sub-system or technology. Rather, what is needed is a new approach that relies on explicitly modeling, analyzing and designing these multi-layered systems in a dynamic context.

To understand CES, one must look at many phenomena that are not traditionally considered an inherent aspect of engineering and which require a multidisciplinary approach combining engineering solutions with methods gleaned from science, technology, and the social sciences. The outlook must take a long-term, lifecycle view of systems rather than optimize individual processes in isolation. CES research addresses real-life challenges such as rebuilding critical infrastructures, working toward energy sustainability and security, and managing global supply chains and explores the ways in which individuals, networks and societies manage and interact with these systems.

## Complex Engineering Systems in Saudi Arabia and the Region

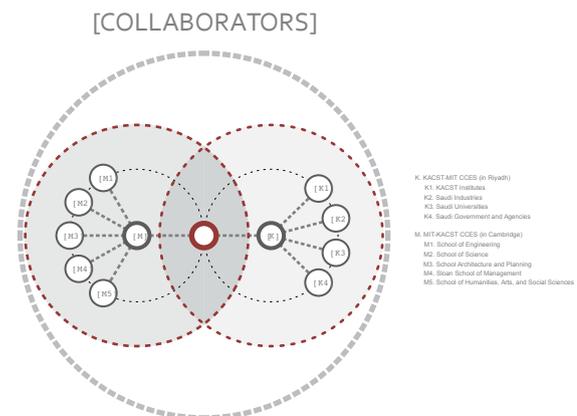
In recent years, the Kingdom of Saudi Arabia has made the development of the knowledge economy of the country a top national priority, with strong support and funding for a more prominent role for science and technology in higher education and research. The nation's efforts are targeted at making Saudi Arabia a hub for world-class institutions of research and learning and an attractive base and relevant partner for international collaborations in the knowledge-based, globalized economy. Ultimately, the goal is to increase Saudi Arabia's social and economic well-being by giving it a competitive advantage in international science- and technology-based innovation, with the accompanying spillover effect on the rest of the domestic economy.

Furthermore, as part of its ambitious plans to diversify the economy away from petroleum exports over the next two decades and in an attempt to transform itself into an industrial powerhouse, Saudi Arabia has embarked on constructing several bold and highly complex engineering systems that include transportation infrastructures, electrical grids, and brand new futuristic cities. These projects all result in large-scale systems that have a high degree of engineering and organizational complexity and will inevitably face multidimensional uncertainty over their long lives, from constantly changing technologies to financial and political exigencies of the globalized economy.

## Collaborators

CCES centers at KACST and MIT will partner with academic institutions, government entities and industry players to tackle challenges faced by such entities or the general public. CCES with its collaborators will address problems that are crucial and realistically solvable, as well simulate new approaches and test theories in the real world with organizations that present such opportunities.

A network of collaborators will be established for every CCES research project in order to match needs and capabilities. This active engagement with collaborators and partners will be a key component of CCES and will provide CCES researchers with local expertise and knowledge while the collaborators will gain the opportunity to access internationally recognized experts, innovative technology and unique research opportunities at KACST and MIT.



## Approaches

Researchers at CCES will bring an engineering mindset to problems that do not lend themselves to purely quantitative or technical solutions. Researchers will seek out fundamental principles that can be used to understand, design, and implement engineering systems. Tackling engineering systems challenges will also require new framing and modeling methodologies, which comprise what we refer to as engineering systems approaches.

Approaches can be viewed as “lenses” or “sets of methods and tools” through which particular problems in the domains are viewed and tackled. These include approaches such as uncertainty modeling and risk management, life cycle analysis, computational design and simulation, and network & flow analysis to name a few.

## Joint Research Opportunities

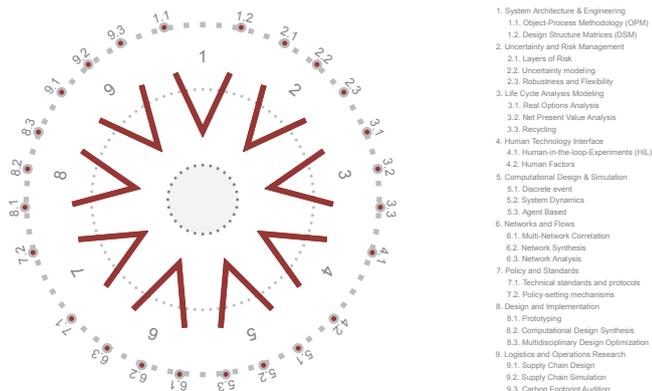
The collaboration between KACST and MIT will provide the opportunity to develop the Complex Systems Engineering field of study for the Middle East. The goals of this collaboration would include knowledge transfer via education, training, publications and industrial collaboration as well as the promotion of the importance and benefits of the study of Complex Engineering Systems. Such collaboration would provide access to advanced research in areas critical to Saudi Arabia's future success.

In addition, the joint effort provides KACST with a competitive edge and a leading role in the real-world application of systems thinking by accelerating the adoption and implementation of best practices in real projects. It can assist KACST in providing an innovative way forward for Saudi industry, academia, and civil services to stimulate growth and new directions in multi-disciplinary research. The goal of such collaboration is to support KACST in becoming a crucial partner for developing sustainable systems solutions that meet the challenges of the twenty-first century and beyond.

The collaboration also provides MIT with the unique opportunities offered by such a fast-developing region for applying, testing, and refining the concepts of complex systems. Unlike many complex systems in North America and Western Europe that are highly constrained by legacy, the systems in Saudi Arabia and the Middle East region are still at a fluid stage of development and susceptible to “technology leapfrogging.”

Through a KACST-MIT collaboration researchers at institutions across Saudi Arabia and the region, working with MIT colleagues, can develop new knowledge as they explore advanced research in systems thinking.

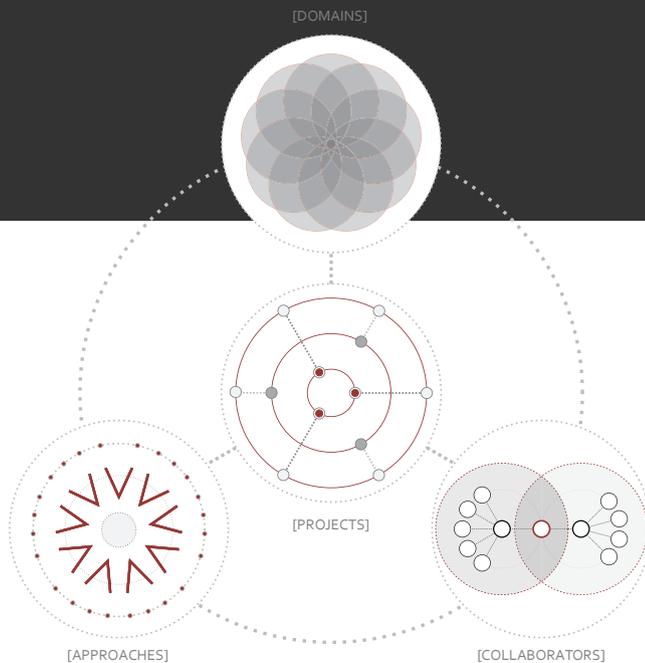
### [APPROACHES]



# CCES Architecture

Engineering advances produce better medicines, enhance food production, supply a bounty of products on store shelves, and speed emergency communications all at lower costs, improving the lives of billions of people throughout the world. These benefits, however, are not delivered by the technological achievements alone, but rather by complex, intertwined engineering systems—systems that integrate people, technology, and services. Therefore the architecture of CCES is deliberately broad and “open.”

Many of the new challenges involving these large, somewhat chaotic systems stem from the random interactions of people, organizations, and technology—leading to emergent properties over time. To address these challenges, CCES architecture will consist of four main components that identify CCES research: Domains, Approaches, Collaborators and Projects.



# Domains

Over the next 50 years, a billion more people will be demanding modern services, mainly in the cities of the developing world. Systems that provide these services include energy, water, transportation, information and communication, industry, material cycles, education and health care delivery. Improving the effectiveness of these large-scale systems is an important challenge.

The problems CCES will address are situated in one or more domains. Domains are functional areas of applications that have traditionally been self-contained and often evolved independently. While a better understanding of the behaviors of systems within their respective domains is required, to create a truly sustainable complex systems it is important to take an integrated, multi-domain approach. In large-scale complex systems, a number of sub-systems—often also complex and large in their own right—interact and function together. A profound grasp of such interactions along with the individual components is at the heart of the work of CCES.

