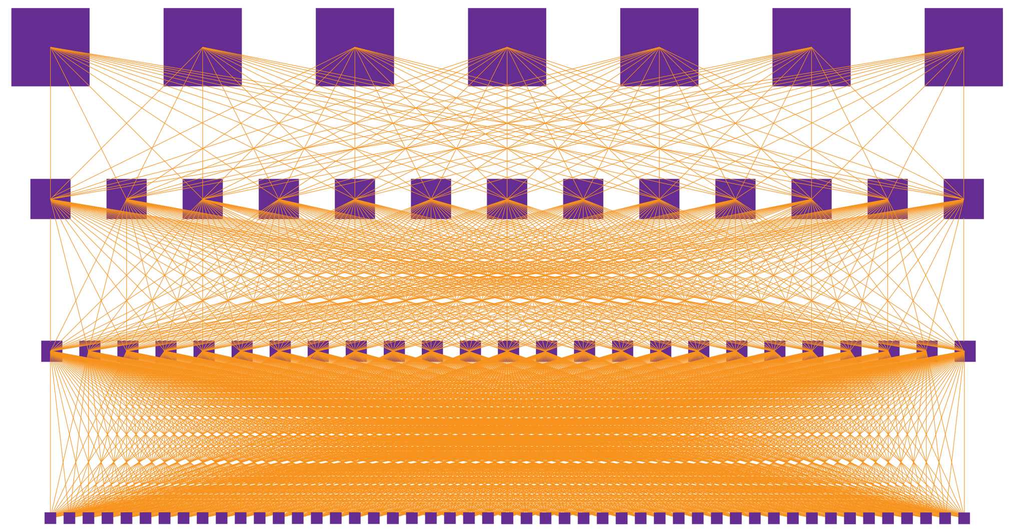

Patterns in Architecture, Cognition, Systems, and Software: Representing and Analyzing Cognition during the Design Process

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Design Challenge

The built environment is increasingly expected to actively contribute to improving human health, well-being, and performance in measurable, predictable, and tailorable ways. Examples of such environments include next-generation operating rooms [1], assitive, robotically augmented patient rehabilitation suites [2], and assistive manufacturing systems [3]. For high-performance buildings with complex program requirements and/or integrated systems, achieving such high-performance environments increasingly requires real-time-interactive sensing, monitoring, actuation, and communication subsystems as well as connection to external networks of systems.

As a result, it is becoming necessary for designers to represent and analyze occupants' anticipated cognitive and physical tendencies when interacting with the building's systems in order to design the cognitive and ergonomic affordances to be offered by the building's interactive systems. That is, the design of high-performance buildings is becoming entangled with user experience design for software-controlled interactive systems. Architects' roles, methods, and tools will have to evolve to participate in the design of such complex, interactive, integrated systems of systems. ***So, what are architects' roles in such design challenges? And, how should we design complex, interactive, architectural systems (CIAS)?***

Designing such building-scale, integrated human/hardware/software/environmental systems will expand the design team to include many other disciplines, especially: human factors engineers, neuroscientists, software developers, and systems engineers. We will have to establish shared modes of analysis, representation, and communication for human-building interactions early in the design lifecycle. ***This dissertation research examines these challenges and proposes a framework for bounding the challenges and a design method + tool for designing complex, interactive, architectural systems (CIAS), which we call CIAS-DM (DM = Design Methodology).***

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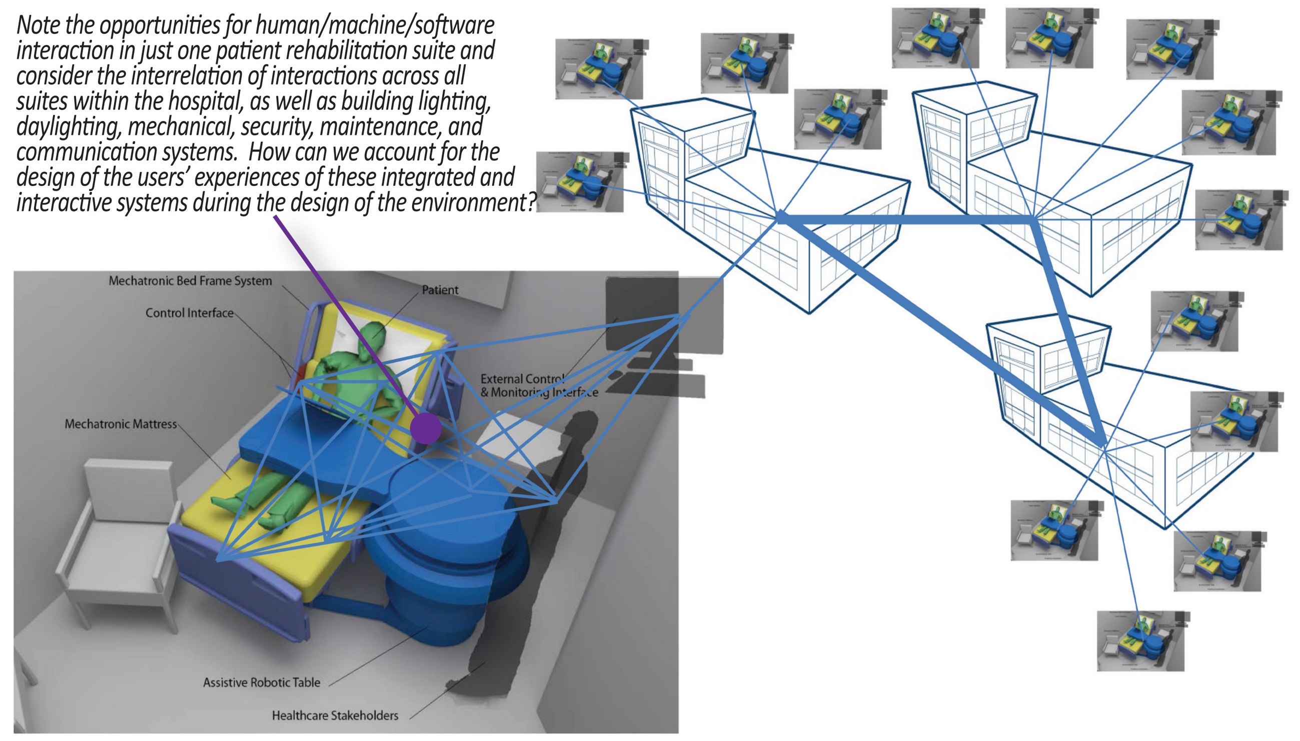
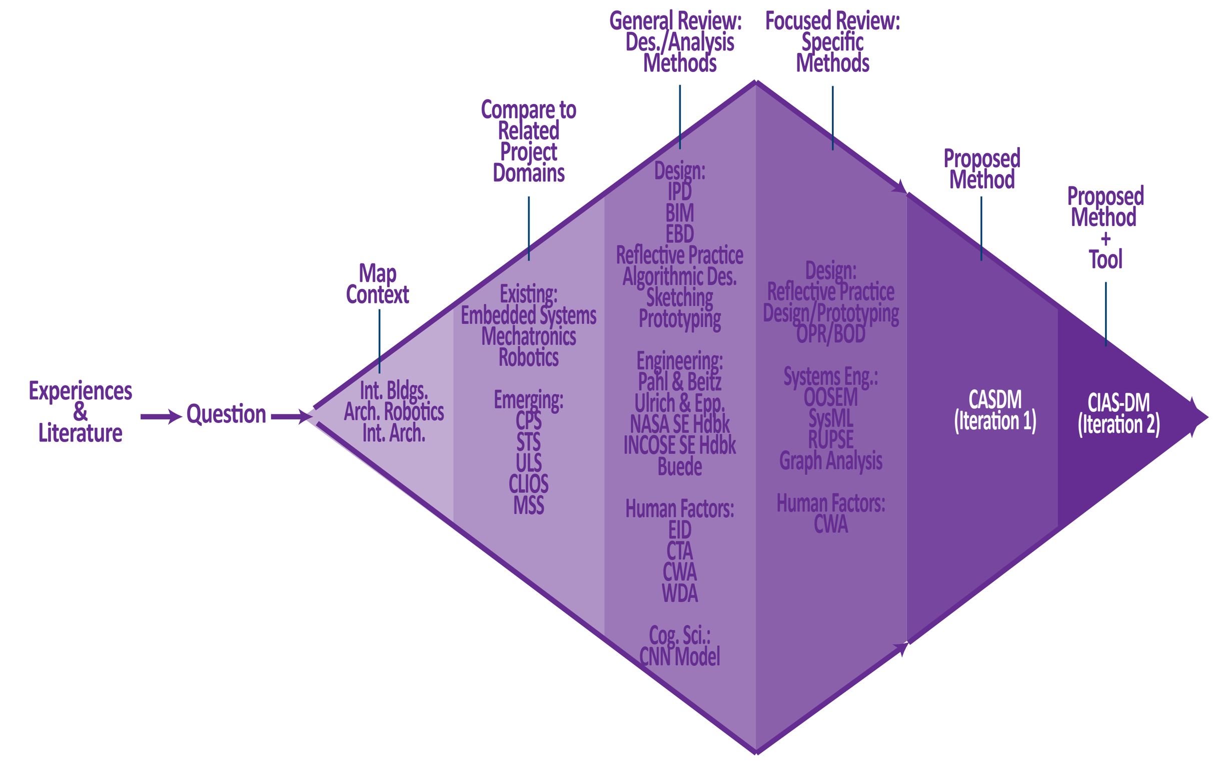
Example of a CIAS Design Challenge



Characteristics of CIAS: 1) a component of a larger complex/interactive system of systems while being composed of a system of systems; 2) real-time hardware/software interactions amongst and between internal and external systems to function successfully; 3) real-time human-machine-software interactions are essential to meeting user goals and expectations.

Challenges of Designing CIAS: 1) CIAS exist at multiple scales of concern simultaneously, 2) the very large degrees of freedom of the system, 3) real-time interactivity between users, physical & virtual environments, 4) the distributed nature of the system of systems, 5) layers of interconnected sub-systems, some of which cannot be completely modularized, 6) the system's openness to unknown and unknowable systems external to itself, 7) the extensive collaboration required to design CIAS, 8) imperfect understanding of goals, use cases, constraints, and/or missing requirements, 9) reliability, 10) robustness, 11) scalability, 12) adaptability, 13) safety, 14) lack of adequate design and analysis artifacts, 15) non-traceable functionality, and 16) inability to optimize across all systems simultaneously.

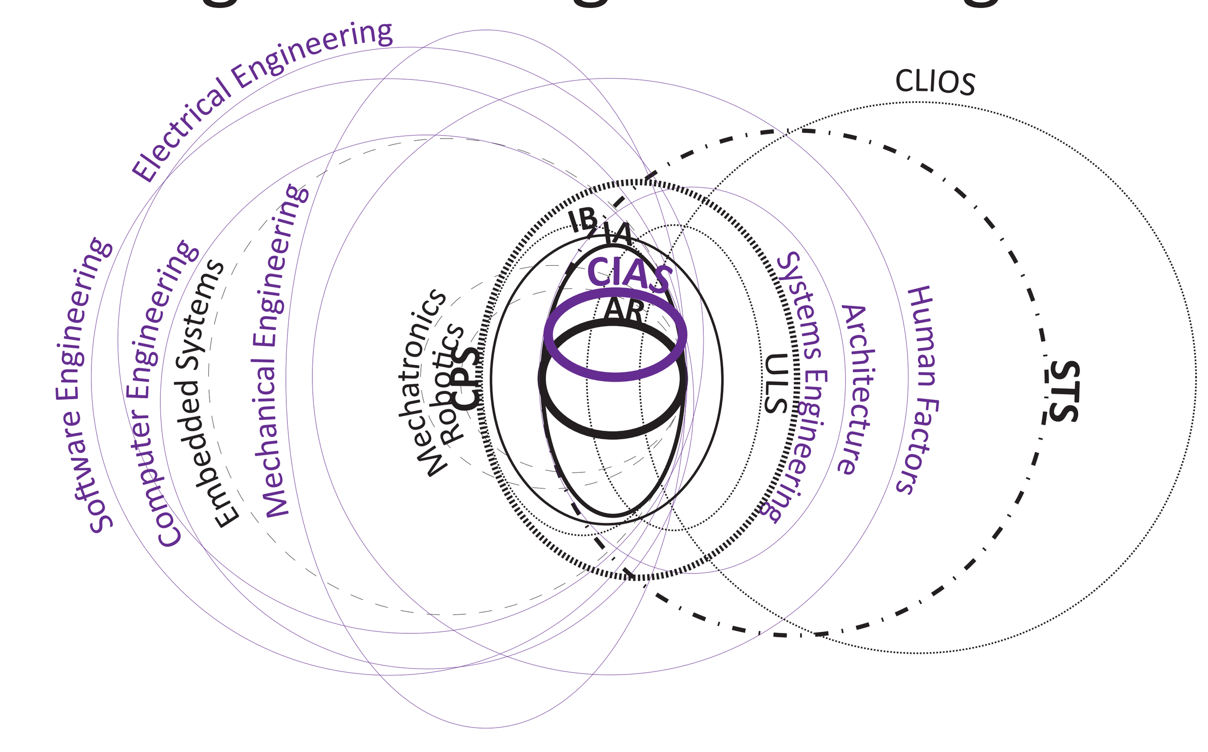
Mapping the Design Domain



Structure of the Research: In order to understand the design challenge, the emerging architectural project types of intelligent buildings (IB), interactive architecture (IA), & architectural robotics (AR) were compared to related existing and emerging interactive/intelligent project domains. From this review, characteristics of and methods for developing such interactive/intelligent systems were reviewed and compared to architectural design methods. Finally, a new method + tool for architectural design was developed. This year, we will iterate, refine, and test this method through a series of case studies.

Lessons from the Literature: The design of complex, interactive systems requires a mixed top-down/bottom-up approach. Top-down approaches (rational, prescriptive, predictive) help to establish a common set of goals, use cases, requirements, and afford collaboration and predictive modeling across large systems of systems --- but unfortuntely are subject to data overload and are worthless if the underlying assumptions and goals are wrong. Conversely, bottom-up approaches (intuitive, agile, iterative & incremental) are good at developing working solutions quickly, uncovering the right questions, assumptions, and goals, and limiting the degrees of freedom of the challenge --- but unfortunately are difficult to execute across multiple subsystems in a coordinated way. Thus the two modes of design and analysis are complementary and required for the design of CIAS. ***In response, we developed a mixed top-down/bottom-up method + tool called CIAS-DM.***

Bounding the Design Challenge

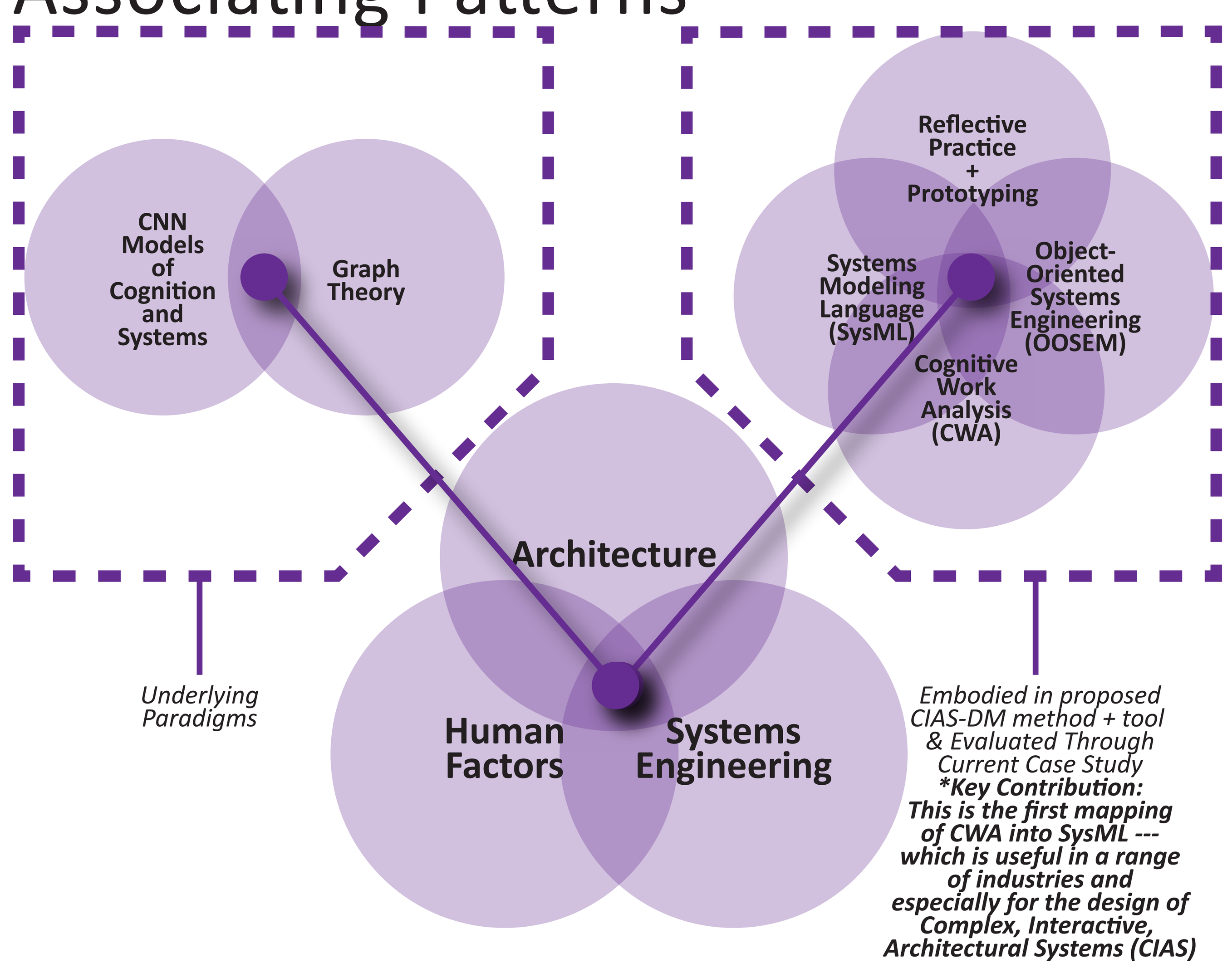


Mapping CIAS: We found CIAS to be a subset of several existing and emerging project domains, but especially the emerging project domains of cyber-physical systems (CPS) and socio-technical systems (STS).

Cyber-physical systems (CPS) are, "...engineered systems that are built from and depend upon the synergy of computational and physical components. Emerging CPS will be coordinated, distributed, and connected, and must be robust and responsive. Examples of the many CPS application areas include the smart electric grid, smart transportation, smart buildings, smart medical technologies, next-generation air traffic management, and advanced manufacturing. CPS will transform the way people interact with engineered systems, just as the Internet transformed the way people interact with information [4].

Socio-technical systems (STS) are defined as having the following relationships between social and technical systems: 1) the technical component can be specified, its behavior modeled, and it can structure how work is done; the social component cannot be specified and must be incrementally evolved in symbiosis with the technical component in order to result in an effective, efficient, robust system [5].

Associating Patterns



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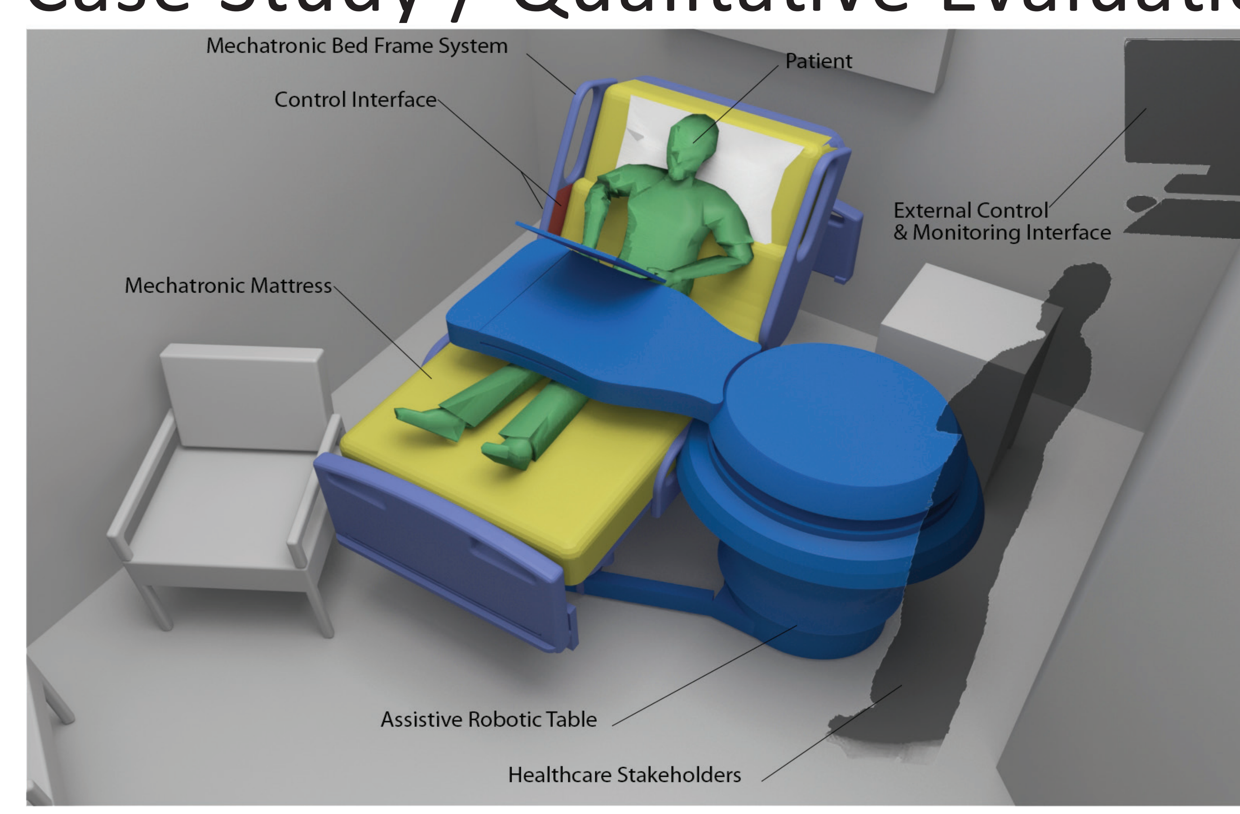
Case Study / Qualitative Evaluation



Rehabilitation Patient Room Ecosystem of Intelligent/Responsive/Interactive Systems: In order to evaluate the CIAS-DM method + tool, we needed a case study that represents sufficient complexity and interactivity without being unmanageable within the scope of a dissertation. We chose to evaluate use of the method + tool with respect to the pre-design services scoping and the criteria design [6] of an intelligent/responsive mattress which participates in an ecosystem of assistive patient room technologies in support of the rehabiliation of the patient as well as the care provided by hospital staff.

Evaluation of the CIAS-DM is qualitative and uses the Validation Square Research Design Method [7] with influences from Design Science Research [8, 9]. That is, we are evaluating the usefulness of CIAS-DM with respect to the purpose of developing complete, consistent, and correct goals, use cases, and requirements, as well as its usefulness during criteria design.

CIAS-DM Method Summary

STEP 1: Review Owner's Project Requirements (OPR) & Identify: Goals, Use Cases, Requirements, system of systems to which system of interest belongs, sub-systems of the system of interest, & draft Basis of Design (BOD) [10]
STEP 2: Diagramming Activities: ***Abstract Decomposition Space (ADS)*** followed by the ***Decision Ladder (DL)*** [11, 14]
STEP 3: Refine products of STEP 1 based upon information gained from STEP 2 and revise Goals, Use Cases, Requirements, and BOD
STEP 4: Purposive Sketch Analysis (***Look & Feel & Roles*** of system of interest, suprasystems & subsystems) [12, 13]
STEP 5: Refine products of STEP 3 based upon information gained from STEP 4 and revise Goals, Use Cases, Requirements, ADS, DL, and BOD
STEP 6: Diagramming Activity: ***Strategies Activity Diagram (SAD)*** [15]
STEP 7: Refine products of STEP 5 based upon information gained from STEP 6 and revise Goals, Use Cases, Requirements, ADS, DL, Purposive Sketches, and BOD
STEP 8: Assess traceability: can all requirements be allocated to at least one task/scenario/use case/goal/system component/function? Map relationships among all and then review all supporting documents as necessary.

Method + Tool: CWA Mapped Into SysML

Systems Modeling Language (SysML) [16] is our representational framework because it: 1) affords tracing design goals, use cases, and requirements for very large systems; 2) has checking and validation functions; and 3) can execute simulations of system behavior in conjunction with other software simulation environments such as Siemens NX and MatLab/Simulink (even rhino+grasshopper). ***Thus for the design of complex architectural systems, using SysML is an evolution in how we document, analyze, communicate, and test designs against the project goals, use cases, and requirements.***

In addition, the cognitive dimensions of designing interactive architectural systems can be addressed by implementing cognitive work analysis (CWA) [14, 15] tools within SysML. Mapping CWA into SysML is the primary contribution of this research. Three CWA tools have been implemented within SysML through new analysis diagrams & associated tools. The value of representing the cognitive and ergonomic dynamics of the interactive systems within SysML is in helping designers think through, document, share, and test against a large set of ever-evolving interactive environmental affordances, user goals, and requirements from early in the project lifecycle.

CIAS-DM incorporates the following CWA [14, 15] tools within SysML: 1) ADS maps what the system is (components) and what it does (functions); 2) DL maps the user goal structures & knowledge states needed to interact with the system; 3) SAD maps DL to ADS and finds gaps in the model.

These design/analysis activities help designers forecast and refine how the system can be used and is meant to be used.

In addition, iterative design/prototyping/sketching activities [12, 13] (bottom-up design/analysis methods) are interwoven with the SysML/CWA activities (top-down design/analytic methods) to focus the scope of work, limit degrees of freedom of the design challenge, and intuit latent needs.