Chapter 3
Design Science Research Frameworks

People sometimes ask me what they should read to find out about artificial intelligence. Herbert Simon's book Sciences of the Artificial *is always on the list I give them. Every page issues a challenge to conventional thinking, and the layman who digests it well will certainly understand what the field of artificial intelligence hopes to accomplish. I recommend it in the same spirit that I recommend Freud to people who ask about psychoanalysis, or Piaget to those who ask about child psychology: If you want to learn about a subject, start by reading its founding fathers.*

– George A. Miller, Complex Information Processing

3.1 Understanding the Natural and Artificial Worlds

The founding father of design science was Herbert E. Simon. Well known for his work on AI, decision making, and economics, Simon wrote a thought-provoking book called *Sciences of the Artificial* in the 1960s (Simon 1996). His profound insight was that certain phenomena or entities are "artificial" in the sense that they are contingent to the goals or purposes of their designer. In other words, they could have been different had the goals been different (as opposed to natural phenomena which are necessarily evolved given natural laws). He further posits: Since artifacts are contingent, how is a science of the artificial possible? How to study artifacts empirically? On the other hand, Simon also deals with the notion of complexity. This is necessary because artificiality and complexity are inextricably interwoven.

We are all familiar with natural science (especially physics and biology) but the world around us is mostly man-made, i.e., artificial. It evolves with mankind's goals. So science must encompass both natural and goal-dependent (artificial) phenomena. Simon in his book discusses how to relate these two. There are two perspectives on

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artifacts, synthetic vs. analytic. The *science of the artificial* is really the science (analytic or descriptive) of engineering (synthetic or prescriptive).

Artifacts

- are synthesized,
- may imitate appearances of natural things,
- can be characterized in terms of functions, goals, adaptation, and
- are often discussed in terms of both imperatives and descriptives.

3.2 Toward a Theory of Complex Systems

Simon's seminal work gives us first clues toward understanding what he called "complex systems." Fulfillment of purpose involves a relation between the artifact, its environment, and a purpose or goal. Alternatively, one can view it as the interaction of an inner environment (internal mechanism), an outer environment (conditions for goal attainment), and the interface between the two. In this view, the real nature of the artifact is the interface. Both the inner and outer environments are abstracted away. The science of the artificial should focus on the interface, the same way design focuses on the "functioning."

Simulation is the imitation of the interface and is implied by the notion of artificiality. Simulation can also be viewed as adaptation to the same goal. It can be used to better understand the original (simulated) entity because simulation can help predict behavior by making explicit "new" knowledge, i.e., knowledge that is indeed derivable but only with great effort. Simulation is even possible for poorly understood systems by abstraction of organizational properties.

Computers are organizations of elementary components whose function only matters. They are a special class of artifacts that can be used to perform simulations (in particular of human cognition). They can be studied in the abstract, namely using mathematics. Yet, they can and must also be studied empirically. Their study as an empirical phenomenon requires simulation (example of time-sharing systems). In conclusion, the behavior of computers will turn out to be governed by simple laws, the apparent complexity resulting from that of the environment they are trying to adapt to.

In his book, Simon notices that complexity is a general property of systems that are made of different parts and that the emergent behavior is hard to characterize.

In the first part of his book he argues that complexity takes the form of hierarchy and that hierarchical systems evolve faster than nonhierarchical ones. Very generally, a hierarchy is a recursive partition of a system into subsystems. Examples of hierarchies are common in social, biological, physical, and symbolic (e.g., books) systems. In biological systems, it is argued that hierarchical systems evolve faster because the many subsystems form as many intermediate stable stages in the process. Similarly in the problem-solving activity, mainly a selective trial-and-error process, intermediate results constitute stable subassemblies that indicate progress.

The second part of his argument is that hierarchies have the property of *near decomposability*, namely that (1) the short-term (high-frequency) behavior of each subsystem is approximately independent of the other components and (2) in the long run, the (low-frequency) behavior of a subsystem depends on that of other components in only an aggregate way. The example of cubicle and room temperature in a building is provided. Other examples are common in natural and social systems.

The last part of the thesis deals with system *descriptions*. It is argued that the description of a system need not be as complex as the system due to the redundancy present in the latter. Redundancy results from the fact that there are only a limited number of distinct elementary components. Complex systems are obtained by varying their combination. Also, the near-decomposability property can be generalized to the "empty world hypothesis" that states that most things are only weakly connected with most other things. Therefore, descriptions may contain only a fraction of the connections. There are two main types of descriptions. State descriptions and process descriptions deal with the world as sensed and as acted upon, respectively. The behavior of any adaptive organism results from trying to establish correlations between goals and actions.

In conclusion, a general theory of complex systems must refer to a theory of hierarchy. And the near-decomposability property simplifies both the behavior of a complex system and its description. In the study of DSR, one repeatedly stumbles upon such complex systems and their behavior. Even to this date, Herbert Simon's work remains the most influential thinking that guides this field of design and artificial sciences.

3.3 Systems Development in Information Systems Research

One of the earliest contribution of design science to IS is the seminal work done by Nunamaker et al. (1990–91). They claim that the central nature of systems development leads to a multi-methodological approach to IS research that consists of four research strategies: theory building, experimentation, observation, and systems development. Theory building includes development of new ideas and concepts and construction of conceptual frameworks, new methods, or models (e.g., mathematical models, simulation models, and data models) (Nunamaker et al. 1990–91). Theories (particularly mathematical models) are usually concerned with generic system behaviors and are subject to rigorous analysis. Experimentation on the other hand includes research strategies such as laboratory and field experiments, as well as computer and experimental simulations. It straddles the gulf between theory building and observation in that experimentation may concern itself with either the validation of the underlying theories or the issues of acceptance or technology transfer. Observation includes methods such as case studies, field studies, and sample surveys that are unobtrusive research operations.

Systems development framework consists of five stages: conceptual design, constructing the architecture of the system, analyzing the design, prototyping (may include product development), and evaluation. The framework is shown in Fig. 3.1.

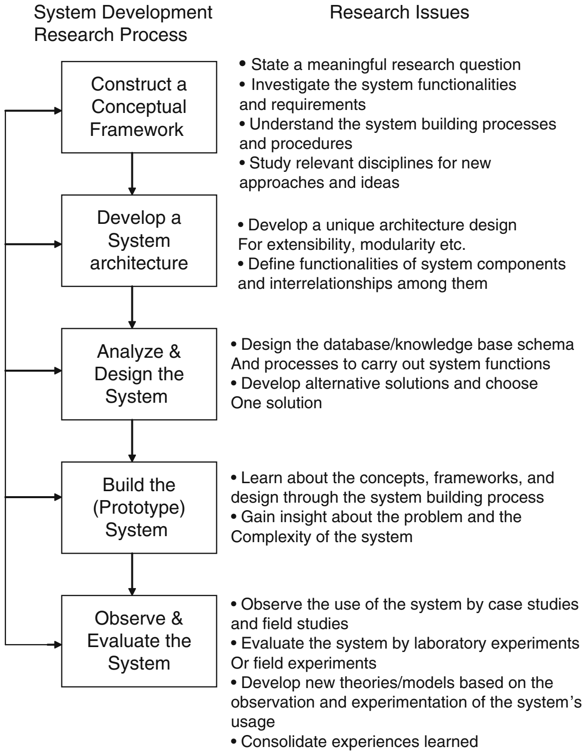

Fig. 3.1 System development research model (adopted from Nunamaker et al. (1990–91))

3.4 The General Design Cycle

Takeda et al. (1990) have analyzed the reasoning that occurs in the course of a general design cycle (GDC). Vaishnavi and Kuechler (2004) have extended this analysis to explicate the knowledge generated in a design effort and apply the cycle specifically to design science research (Vaishnavi and Kuechler 2007) as illustrated in Fig. 3.2.

In this model, all design begins with awareness of problem. The problem genesis can be from many places (we discuss this later in the book). Here you not only identify the problem but also define it. The next stage is a preliminary suggestion for a problem solution that is abductively drawn from the existing knowledge or theory based on the problem area or developed using an appropriate research methodology.

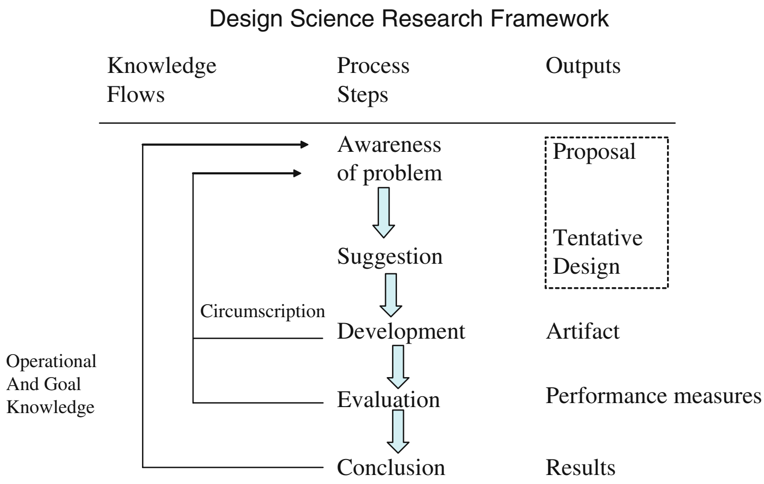

Fig. 3.2 Reasoning in the general design cycle (adopted from Vaishnavi and Kuechler (2007))

Once a tentative design is settled on, the next stage is actual development. This is a creative stage where the design is further refined and an actual artifact is produced through many iterations. This is the only phase of GDC that requires a constructivist methodology (Vaishnavi and Kuechler 2007).

Once an implementation (or prototype) is ready, it isevaluated according to functional specification implicit or explicit in the suggestion. Empirical methods are often used in evaluation. It is important to determine how well an artifact works (Hevner et al. 2004), and researchers should use methods and techniques similar to theory testing (March and Smith 1995) including action research, controlled experiments, simulation, or scenarios. There are iterations and feedback involved in these stages cited as circumscription. Finally a project is terminated and concluded.

3.5 Action Research Framework

Action research is an established research method in use in the social and medical sciences since the mid-twentieth century (Baskerville 1999). Action researchers are among those who assume that complex social systems cannot be reduced for meaningful study. The fundamental contention of the action researcher is that complex social processes can be studied best by introducing changes into these processes and observing the effects of these changes (Baskerville 1999).

In its origins, the essence of action research is a simple two-stage process:

- First, the diagnostic stage involves a collaborative analysis of the social situation by the researcher and the subjects of the research. Theories are formulated concerning the nature of the research domain.

- Second, the therapeutic stage involves collaborative change experiments. In this stage changes are introduced and the effects are studied.

Baskerville (1999) in his tutorial presents the five phases of action research process: (1) diagnosing, (2) action planning, (3) action taking, (4) evaluating, and (5) specifying learning. There are cyclical iterations between these stages and as one can see, there are synergies with GDC and other DSR frameworks. We discuss action design in chapter 13 of this book.

3.6 The Design Science Research Methodology (DSRM)

Peffers et al. (2008) propose and develop a design science research methodology (DSRM) for the production and presentation of DS research in IS. This effort contributes to IS research by providing a commonly accepted framework for successfully carrying out DS research and a mental model for its presentation. It may also help with the recognition and legitimization of DS research and its objectives, processes, and outputs and it should help researchers to present research with reference to a commonly understood framework, rather than justifying the research paradigm on an ad hoc basis with each new paper.

The final objective of a DSRM process is to provide a mental model for the characteristics of research outputs. "A mental model is a "small-scale [model]" of reality . . .[that] can be constructed from perception, imagination, or the comprehension of discourse. [Mental models] are akin to architects' models or to physicists' diagrams in that their structure is analogous to the structure of the situation that they represent, unlike, say, the structure of logical forms used in formal rule theories (Johnson-Laird and Byrne 2007)." Outcomes from DS research are clearly expected to differ from those of theory testing or interpretative research and a process model should provide us with some guidance, as reviewers, editors, and consumers, about what to expect from DS research outputs. March and Smith (1995) contributed to this expectation with their ideas about research outputs. Hevner et al. (2004) further elaborated on this expectation by describing DS research's essential elements. A mental model for the conduct and presentation of DS research will help researchers to conduct it effectively.

The DS process includes six steps: problem identification and motivation; definition of the objectives for a solution, design, and development; demonstration; evaluation; and communication.

Activity 1. *Problem identification and motivation.* Define the specific research problem and justify the value of a solution. Since the problem definition will be used to develop an artifact that can effectively provide a solution, it may be useful to atomize the problem conceptually so that the solution can capture its complexity. Justifying the value of a solution accomplishes two things: it motivates the researcher and the audience of the research to pursue the solution and to accept the results and it helps to understand the reasoning associated with the researcher's understanding of the problem. Resources required for this activity include knowledge of the state of the problem and the importance of its solution.

Some of the researchers explicitly incorporate efforts to transform the problem into system objectives, also called meta-requirements (Walls et al. 1992) or requirements (Eekels and Roozenburg 1991), while for the others this effort is implicit, e.g., part of programming and data collection (Archer 1984), or implicit in the search for a relevant and important problem. Identified problems do not necessarily translate directly into objectives for the artifact because the process of design is necessarily one of partial and incremental solutions. Consequently, after the problem is identified, there remains the step of determining the performance objectives for a solution.

Activity 2. *Define the objectives for a solution.* Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible. The objectives can be quantitative, e.g., terms in which a desirable solution would be better than current ones, or qualitative, e.g., a description of how a new artifact is expected to support solutions to problems not hitherto addressed. The objectives should be inferred rationally from the problem specification. Resources required for this include knowledge of the state of problems and current solutions, if any, and their efficacy.

All of the researchers focus on the core of design science across disciplines: *design and development*. In some of the research, e.g., Eekels and Roozenburg (1991), the design and development activities are further subdivided into more discrete activities whereas other researchers focus more on the nature of the iterative search process (Hevner et al. 2004).

Activity 3. *Design and development.* Create the artifact. Such artifacts are potentially constructs, models, methods, or instantiations (each defined broadly) (Hevner et al. 2004) or "new properties of technical, social, and/or informational resources (Jarvinen 2007)". Conceptually, a design research artifact can be any designed object in which a research contribution is embedded in the design. This activity includes determining the artifact's desired functionality and its architecture and then creating the actual artifact. Resources required moving from objectives to design and development include knowledge of theory that can be brought to bear in a solution.

Next, the solutions vary from a single act of *demonstration* (Walls et al. 1992) to prove that the idea works to a more formal *evaluation* (Nunamaker et al. 1990–91; Eekels and Roozenburg 1991; Hevner et al. 2004; Vaishnavi and Kuechler 2007) of the developed artifact. Eekels and Roozenburg (1991) and Nunamaker et al. (1990–91) include both of these phases.

Activity 4. *Demonstration.* Demonstrate the use of the artifact to solve one or more instances of the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity. Resources required for the demonstration include effective knowledge of how to use the artifact to solve the problem.

Activity 5. *Evaluation.* Observe and measure how well the artifact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artifact in the demonstration. It requires knowledge of relevant metrics and analysis techniques. Depending on the nature of the problem venue and the artifact, evaluation could take many forms. It could include such items as a comparison of the artifact's functionality with the solution objectives from activity two above, objective quantitative performance measures, such as budgets or items produced, the results of satisfaction surveys, client feedback, or simulations. It could include quantifiable measures of system performance, such as response time or availability. Conceptually, such evaluation could include any appropriate empirical evidence or logical proof. At the end of this activity the researchers can decide whether to iterate back to step three to try to improve the effectiveness of the artifact or to continue on to communication and leave further improvement to subsequent projects. The nature of the research venue may dictate whether such iteration is feasible or not.

Finally, Archer (1984) and Hevner et al. (2004) propose the need for *communication* to diffuse the resulting knowledge.

Activity 6. *Communication.* Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences, such as practicing professionals, when appropriate. In scholarly research publications, researchers might use the structure of this process to structure the paper, just as the nominal structure of an empirical research process (problem definition, literature review, hypothesis development, data collection, analysis, results, discussion, and conclusion) is a common structure for empirical research papers. Communication requires knowledge of the disciplinary culture.

3.7 Concluding Thoughts

A number of different design science research frameworks and methodology are presented in this chapter. The purpose is to provide valuable guidelines that design researchers may consider. But we caution the researcher that these steps or methods are useful only when you are able to apply it to your design situation and problem context. It is important to keep in mind that every design science project requires a certain level of creativity.

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