Externalities of Design Science Research: Preparation for Project Success

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Abstract. The success of design science research (DSR) projects depends upon substantial preparation and foresight. The externalities of DSR projects, however, are too often overlooked or given short shrift as the research team wants to 'hit the ground running' to design and build creative solutions to interesting, real-world problems. Frequently, this rush leads to an incomplete understanding of the opportunities and constraints in the project problem, solution, and evaluation spaces, resulting in significant changes and rework. In this research, we propose a model of four essential externalities for DSR projects. Attention to each externality is vital and requires important preparatory activities that entail attention to external impacts of the project's results. The implications of the DSR Externalities Model are discussed and future research directions suggested.

Keywords: Externalities · Design science research · Knowledge bases · Governance · Operational intervention · Resources · DSR externalities model

1 Introduction

Design science research (DSR) projects address complex problems in the real world that involve the development of an impactful artifact and growth of theory surrounding the artifact, bounded by a well-defined application context [1]. These projects require considerable knowledge of both the problem environment and the scientific foundations underlying solution opportunities. Successful projects require substantial preparation and foresight. DSR *externalities*, or considerations outside of the boundaries of the actual project, may be easily overlooked because of the inherent, wicked nature of the project and the effort it takes to address such wickedness. However, understanding and incorporating relevant externalities into the preparation for a DSR project should lead to more successful development of useful artifacts by minimizing lost time for backtracking and rework (iterations).

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We identify four externalities that are essential for DSR project success: *resources*; *governance*; *knowledge bases*; and *operational intervention.* These externalities are chosen based on the authors' experiences in performing many DSR projects and the hard lessons learned by not addressing them adequately in project preparation. While other important externalities exist, we find these four to be particularly interesting and relevant to DSR success. Thus, the contributions of this paper are to: 1) identify, define, and discuss four key externalities as important, prerequisite considerations for DSR success; and 2) propose an agenda for future research that explicitly studies issues of DSR externalities, so researchers can avoid initiating a DSR project without proper preparation and foresight.

2 Design Science Research Externalities

Design science research projects progress from a problem space to a solution space with iterative cycles of artifact construction and evaluation [2, 3] as shown in Fig. 1. A detailed understanding and description of the research problem and its positioning in the problem space are essential to demonstrate the relevance of the research project. There are two key components that describe the problem space: the application context and the goodness criteria for solution acceptance. The application context information provides a rich description of the problem in context. What is the problem domain? Who are the key stakeholders in the problem space who will impact, and be impacted by, the design solution? Overall, the application context of a DSR project defines an idiographic basis for the dissemination of design knowledge [4].

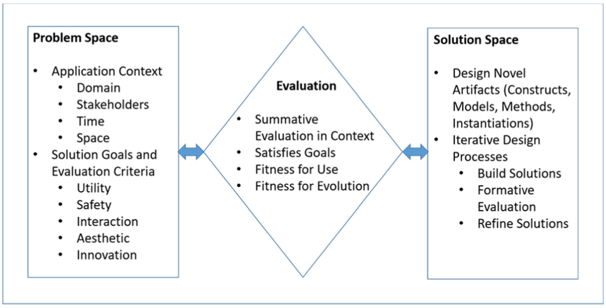

Fig. 1. Design science research process model

The second key design knowledge component in the problem space addresses the solution goals and requirements for how well the new design solves the problem in context. When describing the goodness criteria for the problem, we must recognize the sociotechnical aspects of any practical design solution. Thus, design requirements for satisfactory solutions should include a rich mix of goals from the categories of technology (e.g., security, reliability, performance), information quality (e.g., accuracy, timeliness), human interaction (e.g., usability, user experience) [5], and societal needs (e.g., accessibility, fairness) [6]. The description of these *solution goals and evaluation* *criteria* provides a rigorous set of acceptance criteria for the evaluation of potential design solutions and establishes guidance for both formative and summative evaluation [7, 8].

The solution space produces artifacts to solve problems. It specifically includes both the results and activities of DSR. Results of DSR can take different forms, such as designed artifacts (i.e., constructs, models, methods, and instantiations) as well as design principles or design theories in the form of nascent theories and midrange theories that generalize an understanding of how and why artifacts satisfy the goals of the problem space. Novel knowledge in the solution space can also refer to design processes that encompass build activities that contribute to creating, assessing, and refining the DSR results in iterative build-evaluation cycles. Information on goodness criteria from the problem space is used to guide a goal-driven search to maximize value that is nevertheless constrained by the availability and feasibility of resources.

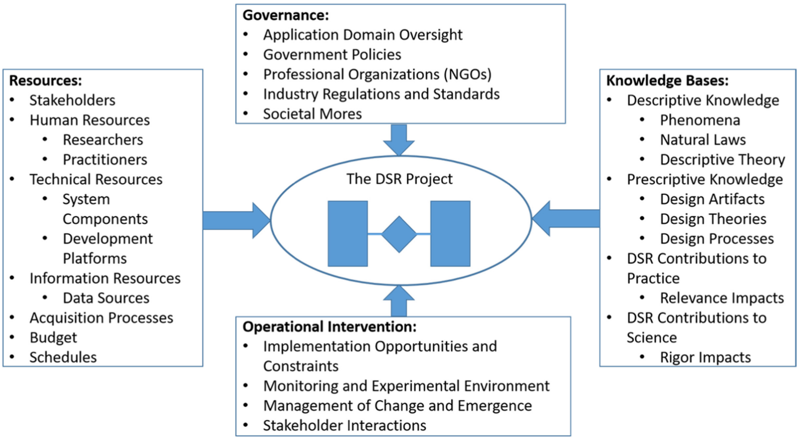

Fig. 2. DSR project externalities model

Evaluations link solutions (in the solution space) to problems (in the problem space) and provide evidence of the extent to which a solution solves a problem using the chosen evaluation method. Given the great variety of different methods and application scenarios for evaluations, transparency of both the process and the results of the evaluation are important issues. Two distinct types of design evaluations are fitness for use and fitness for evolution [9]. *Fitness for use* evaluations assess the ability of a design artifact to perform in the current application context with the current set of goals in the problem space. *Fitness for evolution* evaluations assess the ability of the solution to adapt to changes in the problem space over time. This type of evaluation is critical for application environments in which rapid technology or human interaction changes are inevitable and successful solutions must evolve.

Before commencing the DSR project as seen in Fig. 1, however, essential preparation is needed to reduce the risk of unnecessary design iterations and rework. We propose that there are four key DSR externalities as shown in Fig. 2: *resources*, *governance*, *knowledge bases*, and *operational intervention*, as explored below.

3 Resources Externality

The basic premise of any project management plan is a comprehensive understanding of required resources to complete a successful project [10]. This begins with cataloging available resources (e.g., budget, schedule, human, technical, data) and identifying project stakeholders. Stakeholders have goals, objectives, and values that must be managed via trade-offs to define a set of requirements for system functions and qualities that will lead to an innovative design solution and implementation that meets stakeholder needs. A key activity to prepare for the DSR project is the acquisition of sufficient additional resources in the form of human capabilities, data repositories, and system technologies to achieve both practice and research contributions.

Effective resource identification for DSR projects is often difficult due to the wicked nature of the problem and the emergent behaviors of the solution. The number of iterative diagnosis cycles in the problem space and the number of iterative design and implementation cycles in the solution space are difficult to predict during initial planning [11]. Action design research projects provide additional challenges via requirements to integrate practitioner resources and schedules [12]. An insightful approach to manage the resources externality for DSR projects is to consider the feasibility dimensions of information systems as proposed by Valacich and George [13]. Table 1 summarizes the feasibility dimensions for project resources, identifying the specific considerations needed for managing design science research resources. We specifically add *Innovation Feasibility* to support the scientific knowledge contributions of a DSR project.

4 Governance Externality

Who is looking over your shoulder on the DSR project and who will be impacted by the results? The full range of governance stakeholders in the application domain must be identified and effectively managed. The role of governance provides multiple levels of independent oversight for the development and operations of the desired information systems and clarifies issues of responsibilities and accountabilities. Drawing from governance models by Shneiderman [14–16], we propose a five-level governance hierarchy for DSR project planning.

1. User Governance: The eventual users of the project results will provide requirements on system capability, usability, utility, understandability, and support needs. User focus groups, committees, and embedded practitioners on the DSR project team are sources of user governance needs.
2. Developer Governance: The developers of the technical systems bring rigorous software engineering practices for the building of reliable systems. Good governance supports the effective use of audit trails, static and dynamic analysis tools, verification and validation testing methods, and explainable user interfaces.

Table 1. Feasibility dimensions for DSR project resources

Feasibility dimensions	Description	Manage DSR resources
Technical feasibility	Capabilities of systems technology (hardware, software, infrastructure) and personnel	Capture a complete model of the problem space resources Anticipate resources needed to design novel solution
Economic feasibility	Cost-benefit analysis	Analyze economic constraints and opportunities
Operational/organizational feasibility	Impact of project on organizational structure and work practices	Propose intervention environment for evaluation of solution Operational considerations
Schedule feasibility	Timeframe realistic given skills and availability of participants	Bound DSR project goals and deliverables to match schedule constraints
Legal and contractual/governance feasibility	Legal and regulatory issues and constraints Contracts and legal implications	Incorporate governance and regulatory issues and constraints into artifact designs
Political feasibility	Power structure of stakeholders Impact on organizational environment	Understand design trade-offs to achieve balanced stakeholder satisfaction
Innovation feasibility	Consumption and production of domain knowledge Innovation opportunities Scientific contributions	Structure research questions Communicate new scientific knowledge via publications

3. Management (Inside) Governance: The organization provides a level of governance that promotes safety, privacy, and accountability of the system. Based on the application domain best practices, the organization establishes standard operating procedures for logging system interactions, reporting failures and violations, hiring and training operators, and supporting maintenance and evolution.
4. Independent (Outside) Governance: Depending on the application domain, the new system will fall under a number of independent, outside governance agencies. Attention must be paid to oversight actions and certifications from government regulations, accounting audits, insurance requirements, NGO stakeholders, and professional organizations such as research institutes.
5. Societal Governance: Global issues of ethical behaviors, fairness, diversity, and social consciousness must play a significant role in the design of solutions. Attention to these societal concerns will permeate decisions across all levels of the governance hierarchy.

Identifying stakeholders at all the governance levels during project preparation is time-consuming, but essential, for achieving the goals of usable, reliable, safe, trustworthy, and ethical systems design.

5 Knowledge Bases Externality

A DSR project must appropriately consume existing knowledge and produce new knowledge in the application domain knowledge bases [1, 17]. Depending upon the project research questions, extensive and rigorous interactions with external knowledge bases must be considered and planned early in the project execution. Archival knowledge bases that ground DSR projects include the research literature, data bases, and repositories of IT artifacts and systems. Identifying the appropriate knowledge sources is essential preparation for an effective DSR project. To support effective attention to this externality, six modes of DSR knowledge consumption and production are seen in Fig. 3, and adapted from Drechsler and Hevner [2].

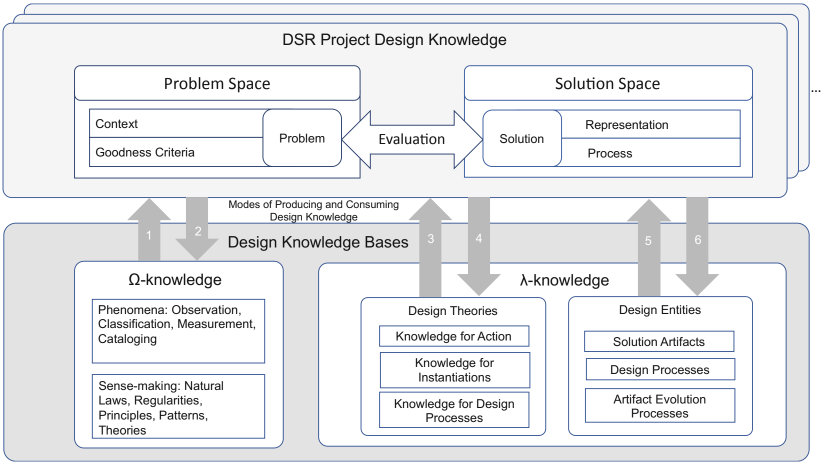

Fig. 3. Modes of DSR project and knowledge bases interactions (Adapted from [2])

Basic knowledge can be represented by two major types: 1) research activities which primarily grow Ω-knowledge (comprising descriptive, explanatory and predictive knowledge), and, 2) research activities which primarily grow λ-knowledge (comprising design knowledge) [17]. The λ-knowledge is divided into two sub-categories. *Design Entities* collect the prescriptive knowledge as represented in the tangible artifacts and processes designed and applied in the solution space. The growing of design theories around these solutions is captured in *Design Theories*. We can describe the interactions of a DSR project with the extant knowledge bases in the following consuming and producing modes:

- **Modes 1 and 2 – Use and Add Ω-Knowledge:** Ω-knowledge informs the understanding of a problem, its context, or the development of a design entity in Mode 1.

Mode 2 involves the testing and building of Ω-knowledge enhancing our descriptive understanding of how the world works given the new design knowledge.

- **Modes 3 and 4 – Use and Add Design Theory:** Solution knowledge, in the form of growing design theory, informs the development of a design entity in Mode 3. Effective principles, features, actions, or effects of a design entity are generalized and codified in solution design knowledge in Mode 4.
- **Modes 5 and 6 – Use and Add Design Entities:** Existing designs and design processes are re-used to inform novel designs of new design entities in Mode 5. Mode 6 contributes new design entities to the knowledge base.

These six modes of producing and consuming knowledge illustrate the multi-faceted opportunities for knowledge accumulation and evolution over time [18] and the importance of how the DSR project interacts with the external knowledge bases.

6 Operational Intervention Externality

To perform a convincing summative evaluation of the design solution, as seen in Fig. 1, the DSR team must plan for an effective operational intervention in the problem application context. What are the opportunities and constraints in the real-world operational environment for evaluation experiments and studies? DSR projects often face significant limitations on the controls they can exert to perform rigorous scientific evaluations [19].

Planning for design solution interventions and summative evaluations must be based on information that matches the research questions to the operational possibilities for evaluation. The DSR project team will identify an appropriate set of evaluation methods [3] to align with the opportunities and constraints of the operational environment. This requires matching evaluation methods to multiple facets of DSR. Besides the research question, the evaluation must match the goals of the project. The evaluation criteria must be specified with respect to the hypotheses and dependent variables.

The application environment impacts and restricts the experimental controls that can be put into place, given the context within which the evaluation is carried out. For example, IRB requirements often restrict the capture and use of identifying information related to a participant. Intentional (and unintentional) capture of identity and supporting information creates an ethical burden for disclosure on the part of the researchers that cannot be trivialized. The stakeholders within the application domain must sign off on experimental evaluation within that domain.

The availability of data sources affects the ability to carry out a proper evaluation. Data might be qualitative or quantitative; primary or secondary. These types and sources of data influence the kind of data analysis that can be conducted as part of the evaluation. Finally, the evaluation skills and availability of evaluation tools impact a project team's ability to perform an appropriate evaluation. In summary, early due diligence on summary evaluation opportunities and constraints must be part of the DSR project's preparation.

7 Exemplar Case Study

During the past decade, one of the co-authors participated in a highly visible DSR project that faced the externalities described in this research [20]. The project's context was a large-scale, multi-disciplinary research program - Uppsala University Psychosocial Care Programme (U-CARE), funded primarily by grants from the Swedish Research Council. The multi-disciplinary program involved researchers and practitioners from the fields of psychology, medicine, information systems, the caring sciences, and economics. The objective of the project is the implementation of a sophisticated software system for online psychosocial care with comprehensive support for online clinical trials. Stakeholder (e.g., patient, provider) privacy concerns make the development and use of the U-CARE system challenging with highly sensitive privacy and accountability requirements. The following sections briefly illustrate how the DSR team managed the four identified DSR externalities.

7.1 Resources

While resource issues of budget and schedule were important for the initiation and continuation of the U-CARE project, we focus here on the challenges of managing the human resources needed to ensure project success. Identifying the stakeholders for such a large, national healthcare endeavor was critical. Based on stakeholder feedback, we quickly realized that no existing software platform would satisfy the needs of the U-CARE community. Thus, the decision was made to design and develop an innovative information system to support online psychosocial care. This required us to build a software development team that included both researchers and professional developers.

The development approach followed Scrum agile methods including bi-weekly sprint meetings with various stakeholders from the U-CARE context. These meetings included researchers, medical doctors, nurses, patient groups, and psychologists who provided feedback on the emerging software design. This process served as formative evaluations of the emerging software; in total, we held 100 + workshops between 2011 and 2015. Psychologists contributed ideas on how to deliver stepped care online, including self-help, cognitive behavior therapy, and peer interaction in forums and chat. Researchers contributed with ideas on how to support randomized controlled trials (RCTs) online, i.e., designing questionnaires, launching them according to study-specific rules, and sending SMS and email reminders to patients and stakeholders to improve adherence to the study. Also, various features to monitor progress in studies and enable therapist decision-making are built into the system to support interactions among psychologists, researchers, and developers.

7.2 Governance

Governance of public healthcare projects was the highest priority externality for the U-CARE project. Early in the project we modeled four groups of stakeholders and their governance requirements for privacy and accountability which we termed *scrutiny*: Societal institutions (e.g., government agencies), Principals (e.g., healthcare providers), Agents (e.g., the staff operating on behalf of principals), and Clients (e.g., community members, including patients). We defined a scrutiny mode for each of the four governance levels. A fundamental proposition is that violation of privacy should be: (i) well-motivated based on organizational responsibility; or (ii) accounted for by someone.

Societal scrutiny explains the processes in society that shape and force stakeholders to comply with ethics and legislative regulations regarding privacy and accountability. In order for the organization to be ready to respond to such external scrutiny, there is a need for ongoing Organizational scrutiny. Such scrutiny requires the organization to stay updated about the external requirements and to set up internal processes to log and monitor use (and misuse) of sensitive information about individuals. Agent scrutiny occurs when staff members responsibly monitor community activity following organizational policies and external requirements. Client scrutiny refers to the community members' peer controls for monitoring system interactions. For example, community members should have the ability to personalize their visibility, to block others' activities, and report unauthorized content.

7.3 Knowledge Bases

The U-CARE DSR goals were to design, build, and evaluate a delivery platform for psychosocial care with support for clinical trials of care protocols. We grounded our research on descriptive and prescriptive theories of privacy and accountability (e.g. [21, 22]). The *technological* research contributions consist of a rich depiction of a process of designing for privacy and accountability, a software system design, and a naturalistic evaluation of the U-CARE platform enacted in practice. We also asserted *theoretical* contributions surrounding a design theory of scrutiny. The project is the first comprehensive, longitudinal DSR study to develop and evaluate a design theory for the development of sensitive online healthcare systems. A full discussion of how we consumed and produced healthcare knowledge is presented in [20].

7.4 Operational Intervention

The intended purpose of the U-CARE platform is to deliver online healthcare to remote locations throughout Sweden. Additionally, it is designed to support clinical trials of experimental healthcare protocols. Thus, from the beginning, we developed a plan for summative evaluations of the platform in actual use with clients, agents, administrators, and regulatory bodies. It was this detailed plan that generated the system requirements for supporting experimental clinical trials. The U-CARE system was used in practice by researchers, psychologists, and patients in 11 research trials for three years (April 2013–September 2016), during which time experimental data were gathered and analyzed. Approximately 3000 patients participated in studies using the software. The practical use of the system over the three years provided a basis for a rigorous naturalistic evaluation of the artifact and its use in practice.

8 Discussion

The DSR Project Externalities Model provides a helpful, albeit incomplete, framework for attending to important externalities in DSR projects. From this starting point, we now propose guidelines and research directions for recognizing and managing externalities. In Fig. 4, we introduce the *prerequisite space* as a project entity, analogous to the problem space and solution space that are well-documented in DSR. The prerequisite space envelopes the DSR project with the essential externalities addressed in the project planning to achieve the research goals. Every project must identify the externalities that apply and commit the resources to manage those externalities throughout the project. Although this might appear to add extra complexity, specifically incorporating this space supports the successful completion of a project, because it acknowledges the substantial preparation and foresight needed by focusing attention on important activities that entail responsiveness to external impacts of the project's results. Table 2 identifies research that considers the prerequisite space and the externalities.

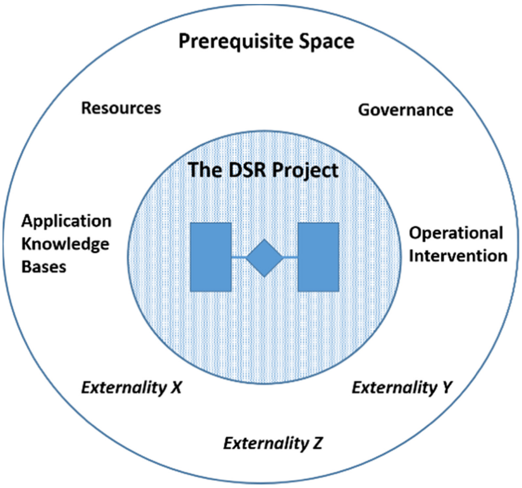

Fig. 4. Externalities addressed in a prerequisite space

Table 2. Future research directions in the prerequisite space

Externality	Research topics
Resources	How do we identify a generic list of resources that might be needed for DSR projects? What type of resource management can help ensure innovative artifacts? How, specifically, are resources impacted due to DSR's wicked nature of the problem and emergent behaviors of the solution? What resources are needed to incorporate innovation feasibility? Will a practice-oriented approach, which identifies the relationships between "practices and their material conditions" and ontological foundations for artifacts help? [23, 24] How can the sociotechnical aspects be recognized? How do we engage stakeholder participation? [12]
Governance	Can we operationalize the five-level governance hierarchy for DSR project planning proposed in this research? Conducting DSR experiences many novel forms of risk. How should the risks inherent in design science research be prioritized and treated? [25] How do we ensure reliability, safety and reporting, trustworthy certification? [16] How do we identify who performs governance activities and what are its boundaries? How do we create social and ethical algorithms that have transparency, accountability, fairness and lack of bias, while consistent with societal norms [16]? How do we manage DSR project risks proactively in formative or ex ante evaluation? [26]
Knowledge bases	Analogous to knowledge bases for design knowledge, do we need, or can we produce, knowledge bases for externalities? How do we know when we have effectively consumed and produced grounding knowledge? How can we focus on naturalistic evaluations? How can we effectively employ modes of knowledge consumption and production? [27] How can we document consumption and production of knowledge bases in different domains? How can we accumulate knowledge of externalities and make it assessable? How can we track design knowledge growth over time? [18] How do we generate prescriptive knowledge by designing and developing an artifact that meets organizational issues and challenges [28] as suggested by Simon [29]?

(*continued*)

Table 2. (*continued*)

Externality	Research topics
Operational intervention	How do we introduce an artifact into an organizational or societal context and identify the potential resulting organizational/societal impact? How can we obtain the foresight needed to assess how artifact introduction could have deliberate organizational/societal affects? [27, 30] How can summative evaluations be performed? [8] How do we identify the "hidden" contextual factors that might exit? [31]

9 Conclusion

Much research on design science research has focused on the development of an appropriate artifact to solve a real-world problem. We propose a model that encompasses four externalities necessary for DSR project success: *resources*; *governance*; *knowledge bases*; and *operational intervention.* Such externalities require substantial preparation and foresight prior to beginning investigations into the problem and solution spaces of the project. Recognizing these externalities may well lead to less jumping into projects without careful considerations of the problem space and the environment, which can potentially restrict the solution space. It can also result in fewer required iterations to arrive at innovative solution artifacts and novel design theories. A set of research questions and challenges emerge, which provide areas for future research.

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