Design Science Research Methods

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Research methodology across the disciplines

• Do these disciplines have the same methodology?
  – Technical science: Build cool stuff; test it; iterate
  – Social science: Observe people, interpret what they do or say; or select a sample, do a lot of statistics; iterate.
    • For social scientists, engineers are slightly autistic tinkerers
    • For technical scientists, social scientists are chatterboxes
  – Physical science: Build instruments, create phenomena, analyze data, create theories; iterate.
    • For physicists, other sciences are like stamp collecting
  – Mathematics: Read, think, write, think; iterate.
    • Mathematicians think that they provide the foundations of civilization
Our approach

• All research in all disciplines is **problem-solving**
• The problems in design science research are **design problems**
  – Goal is to design something useful
  – Research method is the design cycle
• The problems in empirical research are **knowledge questions**
  – Goal is to acquire theoretical knowledge
  – Research method is the empirical cycle

• Wieringa, R.J. (2014) *Design science methodology for information systems and software engineering*. Springer Verlag
Outline

1. What is design science?
2. Research goals and problems
3. The design and engineering cycles
4. The empirical cycle
What is design science?

- Design science is the **design** and **investigation** of artifacts in context
Two kinds of research problems in design science

To design an artifact to improve a problem context

Design software to estimate Direction of Arrival of plane waves, to be used in satellite TV receivers in cars

Design a Multi-Agent Route Planning system to be used for aircraft taxi route planning

Design a data location regulation auditing method

Is the artifact useful?

Problems & Artifacts to investigate

Knowledge, Design problems

Is the DoA estimation accurate enough in this context?

Is it fast enough?

Is this routing algorithm deadlock-free on airports?

How much delay does it produce?

Is the method usable and useful for consultants?

Is the answer true?

To answer knowledge questions about the artifact in context
Reality check

• What research problem(s) are you investigating?
  – Artifact and context

• NB
  – The title of your thesis is the shortest summary of your research project.
  – Often, it mentions the artifact and the context.
Framework for design science

Social context: Location of stakeholders
- Source of relevance.
- Relevance, and money, comes and goes

Goals, budgets

Design science

Improvement design
- Source and destination of theories
- Theories are forever

Existing problem-solving knowledge, Old designs
New problem-solving knowledge, New designs
Existing answers to knowledge questions
New answers to knowledge questions

Answering knowledge questions

Knowledge context:
Mathematics, social science, natural science, design science, design specifications, useful facts, practical knowledge, common sense, other beliefs

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Outline

1. What is design science?
2. Research goals and problems
3. The design and engineering cycles
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Goal structure: example

Social context

To achieve stakeholder goals: Reduce national health care cost

To improve a problem context: To provide mobile home care for the elderly

Design research

To (re)design an artifact: A remote health monitoring system

To (re)design a research instruments: a questionnaire, the setup of a field experiment

To answer knowledge questions: Is it usable? Does it save time? What quality of care is experienced?
Goal structure: example

Social context
- To achieve stakeholder goals
- Utility (sponsor), fun (designer), curiosity (empirical researcher)
- Contributions
- To improve a problem context:

Design research
- To (re)design an artifact
- Contribution
- To (re)design a research instruments
- Contribution
- To answer knowledge questions:
Three kinds of design research questions

1. Design research problems (a.k.a. technical research questions)
   - To improve some kind of artifact in some kind of context.

2. Empirical knowledge questions
   - To ask questions about the real world.

3. Analytical knowledge questions
   - To ask questions about the logical consequences of definitions
Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>

- Reduce my headache
- by taking a medicine
- that reduces pain fast and is safe
- in order for me to get back to work
Template for design problems

- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>

- **Reduce my headache**
- *by taking a medicine*
- *that reduces pain fast and is safe*
- *in order for me to get back to work*
Template for design problems

• Improve <problem context>
• by <treating it with a (re)designed artifact>
• such that <artifact requirements>
• in order to <stakeholder goals>

• Reduce my headache
• *by taking a medicine*
• *that reduces pain fast and is safe*
• in order for me to get back to work
Also works for **research** problems rather than individual practical problems

- Improve *<problem context>*
- by *<treating it with a (re)designed artifact>*
- such that *<artifact requirements>*
- in order to *<stakeholder goals>*

- *Reduce patients’ headaches*
- *by treating it with a medicine*
- *that reduces pain fast and is safe*
- *in order for them to function as they wish*

The problem is now to design an artifact that helps a **class** of stakeholders achieve a **class** of goals.
• The design problem template relates the artifact to the problem context and stakeholder goals, and adds requirements.
Discussion

• Who are the stakeholders of your project?
  – Real or hypothetical: Stakeholders may not know they are stakeholders

• What is/are your top-level design problem(s), using our template?
  – Improve <problem context>
  – by <treating it with a (re)designed artifact>
  – such that <artifact requirements>
  – in order to <stakeholder goals>

• NB some parts may be currently uncertain, fuzzy, or unknown.
• But surely, some parts are currently known!
There is no single “correct” problem statement

• A good problem statement forces the reader to think focused about the artifact while remaining aware of the intended problem context

• Next two examples extracted from two M.Sc theses
• **BPMN Plus**: a modelling language for unstructured business processes.

• The objective of this study is
  – To investigate the way through which unstructured business processes can be modelled and managed without limiting their run-time flexibility.

• Research questions
  – **Q1** What are the differences between structured and unstructured business processes?
  – **Q2** What are the differences between Business Process Management and Case Management in dealing with unstructured business processes?
  – **Q3** What are the capabilities of existing modelling notations to deal with unstructured business processes?
  – **Q4** How to model an unstructured business process while providing run-time flexibility?

  – Improve <problem context in which unstructured business process is to be modelled>
  – by <introducing a modeling language for unstructured business processes>
  – such that <requirements such as run-time flexibility, and ... learnability etc?>
  – in order to <stakeholder goals, e.g. provide better process improvement advice to clients>
Outline

1. What is design science?
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Implementation evaluation =
Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Treatment validation

- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!
Implementation is introducing the treatment in the intended problem context

• If problem context is a real-world context.... implementation of a solution is **technology transfer to the real world**.
  – Not part of a research project

• If the problem is to learn about the performance of a design ... Implementation of a solution is the **construction of a prototype and test environment**.
  – Part of a research project
Nesting of cycles

<table>
<thead>
<tr>
<th>Research project: design cycle</th>
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</thead>
<tbody>
<tr>
<td>Problem investigation</td>
</tr>
<tr>
<td>Treatment design</td>
</tr>
<tr>
<td>Treatment validation</td>
</tr>
<tr>
<td>Problem investigation (How to do the validation?)</td>
</tr>
<tr>
<td>Experiment design &amp; validation (design and validate a prototype &amp; test environment)</td>
</tr>
<tr>
<td>Implementation (construction of prototype &amp; test environment, lab or field)</td>
</tr>
<tr>
<td>Evaluation (analyze results)</td>
</tr>
<tr>
<td>Implementation (tech transfer)</td>
</tr>
<tr>
<td>Implementation evaluation (in the field)</td>
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</tbody>
</table>

This is a very special engineering cycle, called the empirical cycle.
Questions?
Design cycle

Real-world problem-oriented research or evaluation research

Real-world implementation evaluation =
Real-world problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Real-world design implementation

Treatment validation

- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Solution-oriented research

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Two kinds of design science research projects

• Problem-oriented research and evaluation research
  – Investigate the **real world** to learn about artifacts and how they are used by stakeholders
    • *How is the UML used in small and medium sized companies?*
    • *What is the cause if large SE projects being late?*
    • *How is RE done in large-scale agile projects?*

• Solution-oriented: technical research
  – Design an artifact, and validate it by simulation
    • *Design & validate a multi-agent system for autonomous route planning*
    • *Design & validate a system for remote health monitoring for the elderly*
    • *Design & validate a requirements engineering technique for agile global software engineering projects*
Example, missing question added

- **BPMN Plus: a modelling language for unstructured business processes.**
- **The objective of this study is**
  - To investigate the way through which the unstructured business processes can be modelled and managed without limiting their run-time flexibility.
- **Research questions**
  - Q1 What are the differences between structured and unstructured business processes?
  - Q2 What are the differences between Business Process Management and Case Management in dealing with unstructured business processes?
  - Q3 What are the capabilities of existing modelling notations to deal with unstructured business processes?
  - Q4 How to model an unstructured business process while providing run-time flexibility?
- “The practical usefulness of newly proposed modelling notation is investigated by demonstrating it with the help of an example.
- **Moreover, the proposed modelling notation is validated by conducting interviews with experienced practitioners.”**
Problem

• Stakeholders? Goals? : BiZZDesign consultants. To provide high-quality consultancy.
• Phenomena? Causes, mechanisms, reasons? BPMN does not allow for modelling flexible business processes; but case-management systems almost impose no constraints. Simple explanation: the languages lack facilities. See Q2.
• Effects? Positive/negative goal contribution? Limits to consultancy advice.

Treatment

• Specify requirements! Omitted research question. May be part of Q2.
• Requirements contribute to goals? Omitted too.
• Available treatments? See Q3.
• Design new ones! See Q4.

Validation  Omitted questions, but done by means of interviews.

• Context & Artifact → Effects? Does it work?
• Effects satisfy Requirements? Does it work as desired?
• Trade-offs for different artifacts? Performance of different languages on similar cases?
• Sensitivity for different Contexts? Performance the designed language in different cases?
Research questions reformulated (and renumbered)

Problem investigation
• Q1 Who are the stakeholders, what are their goals, and what problems do they encounter when modeling unstructured business processes?
• Q2 How to define structured and unstructured business processes?
• Q3 What are the capabilities of BPM and CM systems to deal with unstructured processes?

Treatment design
• Q4 What are the requirements of the language? E.g., usability, utility?
• Q5 What are the capabilities of existing business process modelling notations to deal with unstructured business processes? How do they score on the requirements?
• Q6 Design a language to model unstructured business processes

Treatment validation
• Q7 Can the language model known and expected unstructured business processes?
• Q8 Does it satisfy the requirements? How does that compare the other available languages
Sequence of design cycles to reduce uncertainty & manage cost and risk

• Design the product idea
  – Sketch the problem – design the principle of operation – analytical validation of soundness of the idea

• Sketch the product
  – Describe problem – sketch product architecture – provide argument that this exhibits the necessary mechanisms to produce desired behavior

• Feasibility study
  – Same, but now validate by building small prototype in test environment

• Specify the product
  – Describe problem mechanisms and goals – Specify product requirements and structure – validate analytically and empirically

• Etc.
Recap

- Design science designs and investigates artifacts in context
  - Design problems versus knowledge questions
- Engineering cycle:
  - problem – design – validation – implementation – evaluation
- Design cycle:
  - problem – design – validation
  - Nesting of design cycles to solve subproblems
  - Sequence of design cycles to refine global design
Questions?
Outline

1. What is design science?
2. Research goals and problems
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4. The empirical cycle
Research problems in design science

Design research problems
- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>.

Design cycle
- Problem investigation
- Treatment design
- Treatment validation

2. Empirical knowledge questions
   - To ask questions about the real world: about the problem or about the artifact in context.

3. Analytical knowledge questions
   - Yields definitions, assumptions, theorems.
Empirical knowledge questions

• **Descriptive** knowledge questions:
  – What happened?
  – How much? How often?
  – When? Where?
  – What components were involved?
  – Who was involved?
  – Etc. etc.

• **Explanatory** knowledge questions:
  – Why?
    1. What has *caused* the phenomena?
    2. Which *mechanisms* produced the phenomena?
    3. For what *reasons* did people do this?

Journalistic questions. Yield **facts**.

Beyond the facts. Yields **theories**.
Three kinds of explanations: Example

- **Descriptive question: Is the light on?**
  - *Based on observation:* Yes.
  - *When?* Now.
  - *Where?* Here.

- **Explanatory question: Why is it on?**
  1. **Cause:** *because someone turned the light switch, it is on (and not off).* Explains difference with off-state.
  2. *Why does this cause the light to switch on? Mechanism:* *because the switch and light bulbs are connected by wires to an electricity source, in this architecture ..., and these components have these capabilities ...* Explains how on-state is produced.
  3. *By why did someone turn the light on? Reasons:* *Because we wanted sufficient light to be able to read, and it was too dark to read.* Explains which stakeholder goal is contributed to.
Another example: software

- **Descriptive question:** What is the performance of this program?
  - Execution time for different classes of inputs?
  - Memory usage?
  - Accuracy?
  - Etc. etc.

- **Explanatory question:** Why does this program have this performance (compared to others)?
  1. **Cause:** Variation in execution time is caused by variation in input; etc.
  2. **Mechanism:** Execution time varies this way because it has this architecture with these components
  3. **Reasons:** Observed execution time varies this way because users want to be on-line all the time, and therefore provide these inputs
Another example: method

• **Descriptive question:** What is the performance of this method for developing software?
  – Understandability for practitioners
  – Learnability
  – Quality of the result
  – Perceived utility
  – Etc. etc.

• **Explanatory question:** Why does this method have this performance?
  
  1. **Cause:** Difference in understanding of methods by software engineers is attributed to differences in the methods.
  2. **Mechanism:** These differences are explained by the structure of the method and/or the structure of cognition.
  3. **Reasons:** No explanation in terms of reasons here.
Research questions reformulated again

**Problem investigation**

- Q1 Who are the stakeholders, what are their goals, and what problems do they encounter when modeling unstructured business processes?
- Q2 How to define structured and unstructured business processes?
- Q3 What are the capabilities of BPM and CM systems to deal with unstructured processes?

**Treatment design**

- Q4 What are the requirements of the language? *Why?*
- Q5 What are the capabilities of existing business process modelling notations to deal with unstructured business processes? How do they score on the requirements?
- Q6 Design a language to model unstructured business processes

**Treatment validation**

- Q7 Can the language model known and expected unstructured business processes? *Why (not)?*
- Q8 Does it satisfy the requirements? How does that compare the other available languages
Research problems in design science

Design research problems
• Improve <problem context>
• by <treating it with a (re)designed artifact>
• such that <artifact requirements>
• in order to <stakeholder goals>.

Design cycle
• Problem investigation
• Treatment design
• Treatment validation

2. Empirical knowledge questions
   – Descriptive: what, how, when, where, who, etc. → Facts
   – Explanatory: Why → Theories

3. Analytical knowledge questions
   – Yields definitions, assumptions, theorems.
We want to develop theories of problems and of designs

Example of a problem theory:

• A theory of modeling of unstructured business processes
  – Scope of such a theory: the population of all cases in which unstructured business processes are modeled.

Example of a design theory:

• A theory of a particular notation for modeling unstructured business processes
  – Scope of such a theory: the population of all cases in which this notation is used to model an unstructured business process
Two way to go beyond facts: generalization and explanation

Facts

- What happens in these cases?
- What average, variance in this sample?

Explain by
- Causes
- Mechanisms
- Reasons
- Why?

Observed sample

- By analogy from cases
- By inferential statistics from sample

Descriptive theory of the population

- What happens in all cases?
- What average, variance in this population?

Explain by
- Causes
- Mechanisms
- Reasons
- Why?

Unobserved population

Explanatory theory of the case/sample

Explanatory theory of the population
To support generalization and explanation, we need sound empirical research design
Design decisions for research setup

- **Which treatment (if any?)**
- **Which measurements?**
- **Which objects of study?**
- **Which population?**
- **How to sample?**

**Researcher**

**Treatment data**

**Object of Study**

**Sample**

**Measurement data**

- **Treatment instruments & procedures**
- **Measurement instruments & procedures**

- **Representation**

UFPE 26 sept 2016 © R.J. Wieringa
# Research designs

<table>
<thead>
<tr>
<th></th>
<th>Observational study (no treatment)</th>
<th>Experimental study (treatment)</th>
</tr>
</thead>
</table>
| **Case-based:** investigate single cases, look at architecture and mechanisms | **Observational case study**     | • **Expert opinion** (mental simulation by experts),
                                                                                       • **Mechanism experiments** (simulations, prototyping),
                                                                                       • **Technical action research** (experimental use of the artifact in the real world) |
| **Sample-based:** investigate samples drawn from a population, look at averages and variation | **Survey**                      | • **Statistical difference-making experiment** (treatment group – control group experiments) |

Next two slides: Single checklist for all of these research designs
Checklist to establish context

1. Improvement goal?
2. Knowledge goal?
3. Current knowledge?

4. ... 
5. ...
16. ...

Design cycle

Empirical cycle

17. Contribution to knowledge goal?
18. Contribution to improvement goal?

Designing something useful
Answering a knowledge question
This is a checklist for
• research design,
• research reporting,
• reading a report.
App. B in my book &
my web site

Data analysis
12. Data?
13. Observations?
14. Explanations?
15. Generalizations?
16. Answers?

Research problem analysis
4. Conceptual framework?
5. Knowledge questions?
6. Population?

Research execution
11. What happened?

Empirical cycle

Research & inference design
7. Object of study?
8. Treatment specification?
9. Measurement specification?
10. Inference?

Design validation
7. Object of study validity?
8. Treatment specification validity?
9. Measurement specification validity?
10. Inference validity?
Summary

Improvement design

Problems to be investigated, artifacts to be investigated

Knowledge

Answering knowledge questions

**Design research problems**
- Improve <problem context>
- by <treating it with a (re)designed artifact>
- such that <artifact requirements>
- in order to <stakeholder goals>.

**Design cycle**
- Problem investigation
- Treatment design
- Treatment validation

Artifacts → Design cycle → Artefacts

**Empirical knowledge questions**
- Descriptive: what, how, when, where, who, etc. → Facts
- Explanatory: Why → Explanations

**Empirical cycle**
- Research problem analysis
- Research design & validation
- Research execution
- Data analysis

Theories → Empirical cycle → Theories

**Analytical knowledge questions**
Design science research strategy
More robust generalizations

Population

Large samples

Small samples

Idealized

Practical

Scaling up to conditions of practice

Street credibility (works in practice)

More realistic conditions of practice

Laboratory credibility (works in theory)

• Just like New Drug Research
• Scaling up:
  – Single-case mechanism experiment (laboratory simulation)
  – Expert opinion
  – Single-case mechanism experiment (field simulation)
  – TAR (apply technique in a real-world project)
Take-home

• Design science designs and investigates artifacts in context
  – Design problems versus knowledge questions

• Solve design problems with design cycle:
  – Problem investigation – treatment design – treatment validation
  – Nesting and sequencing of design cycles
  – → Useful artifacts for a context

• Answer empirical knowledge questions with the empirical cycle
  – Research problem investigation – research design – validation – execution – analysis
  – Case-based or sample-based designs, observational or experimental designs
  – → Theories about artifact in context

• Research strategy: Scaling up from lab to practice

• Wieringa, R.J. (2014) *Design science methodology for information systems and software engineering*. Springer Verlag


