Classifying Design Enablers
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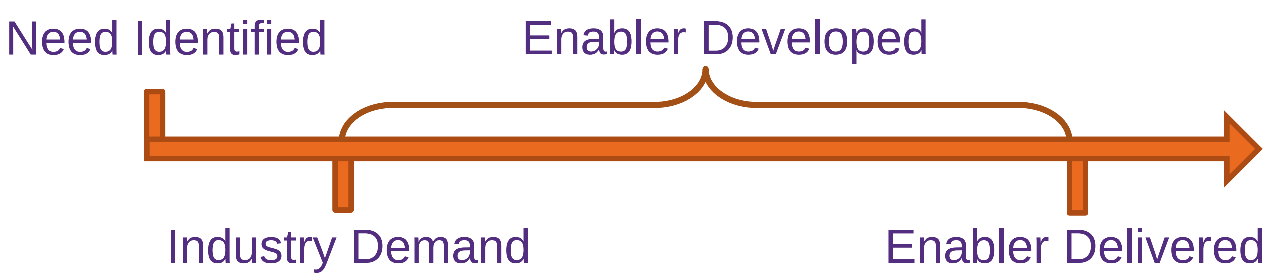
Motivation

- The impact of design enablers on industry is not fully understood
- Current research tends to be limited to the time period during the customer-designer relationship between academia and industry

General Design Enabler Timeline:



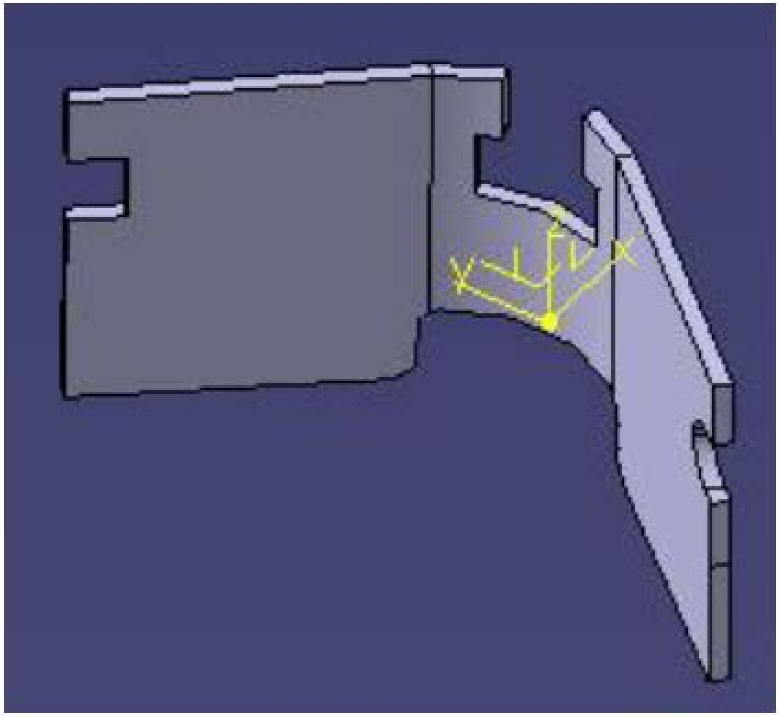
Enabler Deployed?
Why/why not?
How?
To what effect?
To what extent?
Is there more work that needs to be done?

Research Plan

- **Create classification methodology which applies to all design enablers**
- Classify existing design enablers using methodology and determine metrics based on these classifications
  - **Published literature (10 enablers reviewed)**
  - Unpublished documentation from development
  - Interviews with developers within academia
- Determine the impact of these design enablers on impact
  - Interviews with developers within industry
  - Interviews with end-user within industry
- Use metrics to draw connections between development and eventual impact on industry
- Make recommendations for design enabler development and apply to future projects

Design Enabler Classification Questions

- Is it computational?
- What design stage does it aid?
- Does it also enable collaboration?
- Representation
  - Is the vocabulary predefined?
  - What kinds of expressions are used?
  - What is its purpose?
  - Is it mostly explicit or implicit?
- What form of reasoning does it use?
- Development Classifications:
  - How was it demanded?
  - How was it validated?



	Design Tool								Development	
	Comp. (CM, NCM)	Design Stage (PP, CD,ED, DD)	Collab. (CL, NCL)	Rep. Vocab. (PD, UD)	Rep. Express. (TX, MT, IC, PC)	Rep. Purpose (AN, SY)	Rep. Abstract. (EX,IM)	Reasoning (RBR, SBR, ABR, CoBR)	Demand (DA, DPH, DPL)	Valid. (CS, PS, ES, SS, INT)
Lamelle Retrieval System	CM	ED	CL	UD	PC	SY	IM	(ABR)		CS, ES

Is it computational?

- Computational design tool
  - Software developed to enable the product realization process
  - Generally involve some level of automation of the design process for the purpose of creating a model

Either computational (C) or non-computational (NC)

Lamelle Retrieval Tool:

- Software developed CAD query system

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What design stage does it aid?

- Product planning (PP) and clarification of task phase
  - Problem information collected and requirements list is created
- Conceptual design phase (CD)
  - Principle solutions are ideated and evaluated
- Embodiment design (ED)
  - Process of specifying the layout of the principle solutions
- Detail design (DD) phase
  - Detail drawings and production documents of a final solution

Lamelle Retrieval Tool:

- Queries similar Lamelle CAD so that designers can quickly specify new layout

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What it enable collaboration?

- Collaboration refers to the act of joint problem solving (within a team)
  - Distribution of information
  - Mode of communication

Either collaborative (CL) or non-collaborative (NCL)

Lamelle Retrieval Tool:

- Database of CAD files authored and shared among many designers

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Representation: Is the vocabulary predefined?

- Predefined (PD)
  - Limits the user and may force them to express themselves in an unnatural way
- Undefined (UD)
  - Unconstrained vocabulary limits the design enabler to what it is able to interpret

Lamelle Retrieval Tool:

- Users author exemplars unconstrained using CAD to populate query
- User inputs tolerances *assumed* to be mostly unconstrained through interface run query

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Representation: Kinds expressions used?

- Textual (TX)
  - Text
- Mathematical (MT)
  - Numerical or logical
- Iconic (IC)
  - Graphic made up of icons independent of a realistic geometrical representation
- Pictorial (PC)
  - Graphic made up of pictures meant to be a realistic geometrical representation

Lamelle Retrieval Tool:

- Provides CAD to user which acts a realistic geometrical representation

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Representation: What is its purpose?

- Analysis purpose (AN)
  - Designer wishes to learn about what is being represented
- Synthesis purpose (SY)
  - Designer wishes to change what is being represented

Lamelle Retrieval Tool:

- Similar CAD is changed to meet new needs

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Representation: Mostly explicit or implicit?

- Explicit (EX)
  - Information is given to the user
- Implicit (IM)
  - Information must be inferred by the user

Lamelle Retrieval Tool:

- Designer must determine how to change CAD

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What form of reasoning does it use?

- Rule Based Reasoning (RBR)
  - Rules are either used or elicited
- Simulation Based Reasoning (SBR)
  - Simulates final state of design based on initial state
- Analogy Based Reasoning (ABR)
  - If two things are known to be similar in one aspect they must be similar in other aspects
- Constraint Based Reasoning (CoBR)
  - Values limiting relations are applied between objects within a model in order to determine other values

Lamelle Retrieval Tool:

- Tests for similarity using tolerance envelopes

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How was its development demanded?

- Demand Push (DPH)
  - Development of a design enabler is completed within academia before industry confirms need of its development
  - Industry confirmed need
- Demand Pull (DPL)
  - Need for a new design enabler is present within industry which academia then develops to meet this need
- Anticipatory (DA)
  - Development of a design enabler is completed within academia before industry confirms need of its development
  - Industry has not yet confirmed need

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How was it validated?

- Case study (CS)
  - In-depth, objective examination of an uncontrolled, contemporary, and complex phenomenon
- Protocol study (PS)
  - Uses a controlled environment to explore complicated design behaviors and activities using a predefined analysis protocol
- Experimental studies (ES)
  - Compares methods in order to fine tune parameters
- Simulation studies (SS)
  - Mathematical modeling of design processes using computational agents as surrogates for human actors
- Intrinsic validation (INT)
  - Examined based on existing known performance information as reported in literature

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Conclusions and Future Work

- Review of unpublished literature
  - Student files
  - Project Proposals
  - Product Analysis
  - Product Planning Documentation
- Interviews with developers

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References

1. Karl Ulrich and Steven Eppinger, 2011, *Product Design and Development: Fifth Edition*.
2. Pahl G., Beitz W., Blessing L., Feldhusen J., Grote K. H., and Wallace K., 2007, “Engineering Design electronic resource: A Systematic Approach. edn.”
3. Ullman D. G., 2010, *The Mechanical Design Process*, McGraw-Hill, New York, NY.
4. Fadel G., Mocko G., and Summers J., 2016, “Clemson Engineering Design—Applications and Research (CEDAR) Group—Clemson University, Clemson, SC, USA,” *Impact of Design Research on Industrial Practice*, Springer, Cham, pp. 151–168.
5. Summers J. D. D., Anandan S., and Teegavarapu S., 2009, “Introduction of Design Enabling Tools,” *Tools for Innovation*, A. Markman, and K. Wood, eds., Oxford Scholarship Online Monographs, Cambridge, MA, pp. 195–216.
6. Chakrabarti A., and Lindemann U., eds., 2016, *Impact of Design Research on Industrial Practice*, Springer International Publishing, Switzerland.
7. Bracewell R. H., K.Shea, P.M.Langdon, L.S.Blessing, and P.J.Clarkson, 2001, “A Methodology for Computational Design Tool Research,” *Iced01*, (July 2015).
8. Kurtoglu T., Campbell M. I., and Linsey J. S., 2009, “An experimental study on the effects of a computational design tool on concept generation,” *Des. Stud.*, **30**(6), pp. 676–703.
9. Pahl G., Beitz W., Blessing L., Feldhusen J., Grote K. H., and Wallace K., 2007, *Engineering Design: A Systematic Approach*, Springer.
10. Kvan T., 2000, “Collaborative design: What is it?,” *Autom. Constr.*, **9**(4), pp. 409–415.
11. Ostergaard K. J., and Summers J. D., 2009, “Development of a systematic classification and taxonomy of collaborative design activities,” *J. Eng. Des.*, **20**(1), pp. 57–81.
12. Summers J. D., and Shah J. J., 2004, “Representation in engineering design: a framework for classification,” *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, ASME, Salt Lake, UT, p. DTM-57514.

References

13. Summers J. D., 2005, “Reasoning in Engineering Design,” *Proc. ASME IDETC/CIE*, pp. 329–340.
14. Gendreau E. J., Shumaker A. W., Joiner E. M., Griffin A. C., Pritchett C. A., Karmilovich K. A., O’Shields S. T., and Summers J. D., 2015, “Camels and Fennec Foxes: A Case Study on Biologically Inspired Design of Sand Traction Systems,” *ASME IDETC/CIE*, Boston, MA, pp. 2–11.
15. Summers J. D., Anandan S., and Teegavarapu S., 2009, *Introduction of Design Enabling Tools: Development, Validation, and Lessons Learned*, Oxford Press, Cambridge, MA.
16. Le Dain M.-A., Blanco E., and Summers J. D., 2013, “Assessing Design Research Quality : Investigating Verification and Validation Criteria,” *ICED13 19th Int. Conf. Eng. Des.*, (August), pp. 1–10.
17. Yin R., 2003, *Case Study Research: Design and Methods*, Sage, Thousand Oaks, CA.
18. Teegavarapu S., Summers J. D., and Mocko G. M., 2008, “Case study method for design research: A justification,” *ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Brooklyn, NY, pp. 495–503.
19. Jiang H., and Yen C.-C., 2010, “Protocol Analysis in Design Research : a review,” *International Association of Societies of Design Research Conference*, Korean Society of Design Science, Seoul, South Korea, pp. 1–10.
20. Sen C., and Summers J. D., 2012, “A Pilot Protocol Study on How Designers Construct Function Structures in Novel Design,” *5th International Conference on Design Computing and Cognition*, J. Gero, ed., College Station, TX, p. No. 37.
21. Hernandez N. V., Shah J. J., and Smith S. M., 2010, “Understanding design ideation mechanisms through multilevel aligned empirical studies,” *Des. Stud.*, **31**(4), pp. 382–410.
22. Linsey J. S., Green M. G., Murphy J. T., Wood K. L., and Markman a. B., 2005, “Collaborating to Success: An Experimental Study of Group Idea Generation Techniques,” *ASME Des. Theory Methodol. Conf.*, p. 14.
23. Chao K. M., Norman P., Anane R., and James A., 2002, “An agent-based approach to engineering design,” *Comput. Ind.*, **48**(1), pp. 17–27.

References

24. Kannapan S. M., and Marshek K. M., 1992, “A schema for negotiation between intelligent design agents in concurrent engineering,” *Intell. Comput. Aided Des.*, **4**, pp. 1–25.
25. Summers J. D., Divekar A., and Anandan S., 2006, “Towards establishing the design exemplar as a CAD query language,” *Comput. Aided. Des. Appl.*, **3**(1–4), pp. 523–534.
26. Srirangam M., 2007, “A Case Study on the Use of the Design Exemplar as a Search and Retrieval Tool,” Clemson University.
27. Srirangam M., Anandan S., and Summers J. D., 2014, “Development of a geometric model retrieval system: a design exemplar case study,” *Int. J. Comput. Aided Eng. Technol.*, **6**(2), pp. 113–138.

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