In the Age of Collaboration, the Computer-Aided Design Ecosystem is Behind:

An Interview Study of Distributed CAD Practice

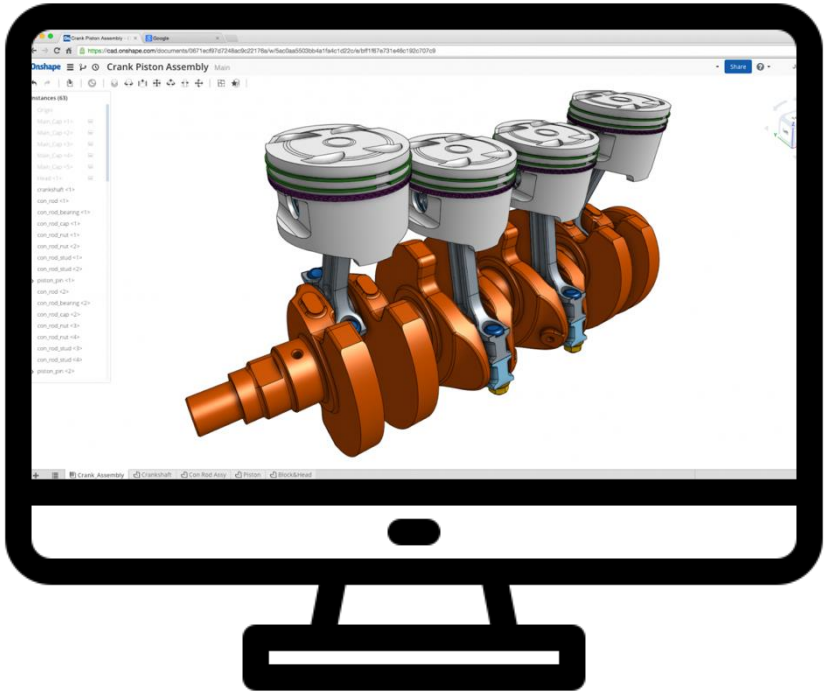
Kathy Cheng, Michal K. Davis, Xiyue Zhang, Dr. Shurui Zhou, & Dr. Alison Olechowski

Product design and development is the process of creating physical products.

CAD is integral to the product development process

Computer-aided design is used to virtually design and test product concepts before fabrication

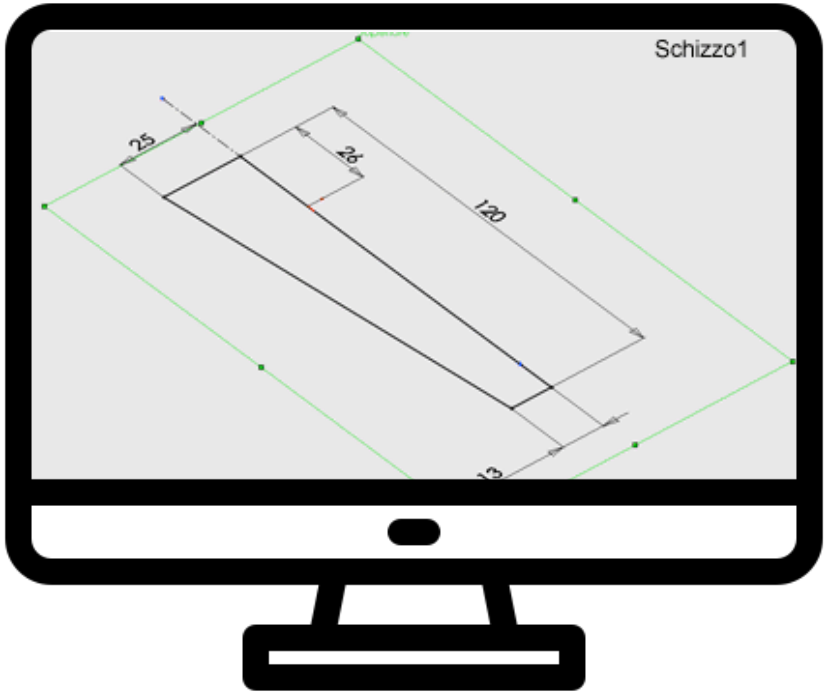
In 2012, it was estimated that 19.3M people use CAD



Stark (2022) ; Jon Peddie Research (2012)

CAD is integral to the product development process

A designer uses constraints to define a sketch, which extrudes to create a solid part. When multiple parts are put together, this creates a product.



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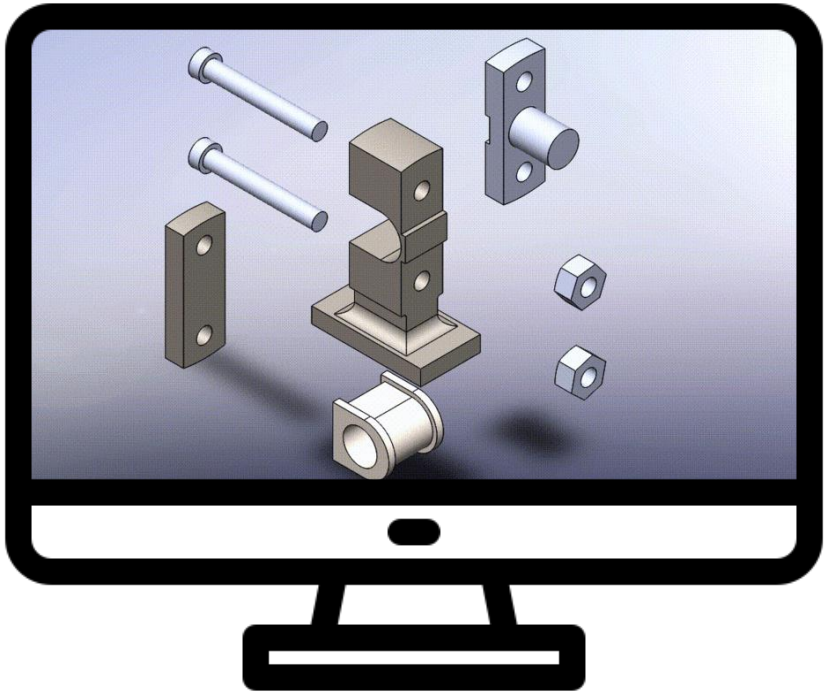
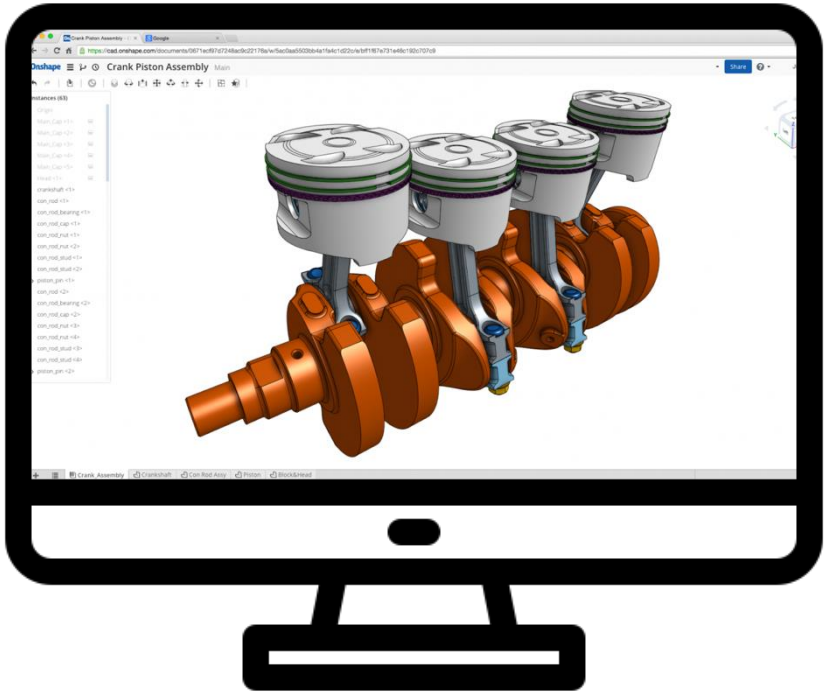


CAD collaboration is challenging

Despite the importance and widespread use of CAD, designers continue to report problems with collaboration



Maher et al. (2017); Warfield (2021); Frazelle (2021)

CAD collaboration is challenging

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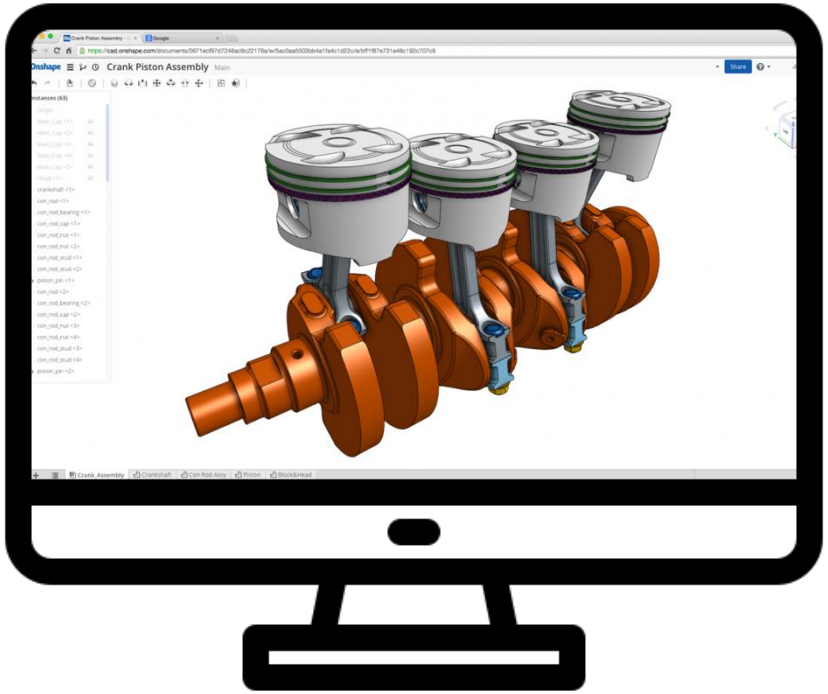
Existing work lacks empirical studies with real CAD practitioners



Maher et al. (2017); Warfield (2021); Frazelle (2021)

Research Questions

RQ1:

What are the collaboration challenges faced by professional CAD designers?

RQ2:

What workarounds are CAD professionals using to alleviate collaboration challenges?

We conducted semi-structured interviews

20 Participants
15 men, 5 women

7.8 Years of experience
on average (SD = 6.8)

55 Minutes
on average

Of the 20 professionals we interviewed…

Industry
- aerospace (25%)
- automotive (20%)
- electronics (20%)

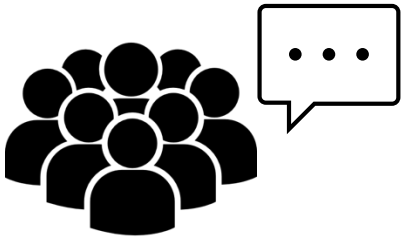
Company Size
- large (85%)
- small (15%)

CAD Software
- NX (35%)
- SolidWorks (35%)
- CATIA (25%)
- Creo (25%)

Data Management
- fully automated (80%)
- manual (20%)

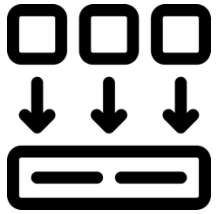
Inductive Coding

1. Gathering statements



2. Labelling data

3. Axial coding



Themes

- Collaborative Design
- Data Management
- Synchronous Communication
- Permissioning

RQ1:

What are the collaboration challenges faced by professionals using distributed CAD?

14 Challenges

RQ2:

What workarounds are CAD professionals using to alleviate collaboration challenges?

6 Workarounds

RQ1: Thematic mapping of challenges

Collaborative Design	Data Management	Synchronous Communication	Permissioning
varied modelling conventions (10)	un-interoperability between systems (12)	cumbersome model presentation (9)	cumbersome access to CAD files (12)
infrequent model uploads (10)	lack of change summarization (7)	lack of conceptual design support (2)	lack of access to CAD software (5)
lack of awareness of dependencies (10)	lack of version control for non-PLM (7)		
lack of awareness of model changes (6)	scattered file management (7)		
lack of synchronous editing support (4)	poor organization of multi-use models (3)		

= number of participants

RQ1: Thematic mapping of challenges

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= number of participants

= corresponding workaround

RQ2: Thematic mapping of workarounds

Collaborative Design	Data Management	Synchronous Communication	Permissioning
standards & best practices (6)	converting to neutral file format (7)		
	using formal data management tools (6)		
	using integrated markup tools (1)		
using assembly configurations (1)	using standard part libraries (3)		

= number of participants

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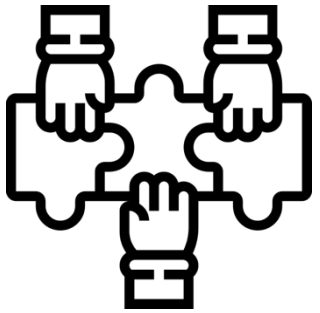
Collaborative Design

- varied modelling conventions
- infrequent model uploads
- lack of awareness of dependencies
- lack of awareness of model changes
- lack of synchronous editing support

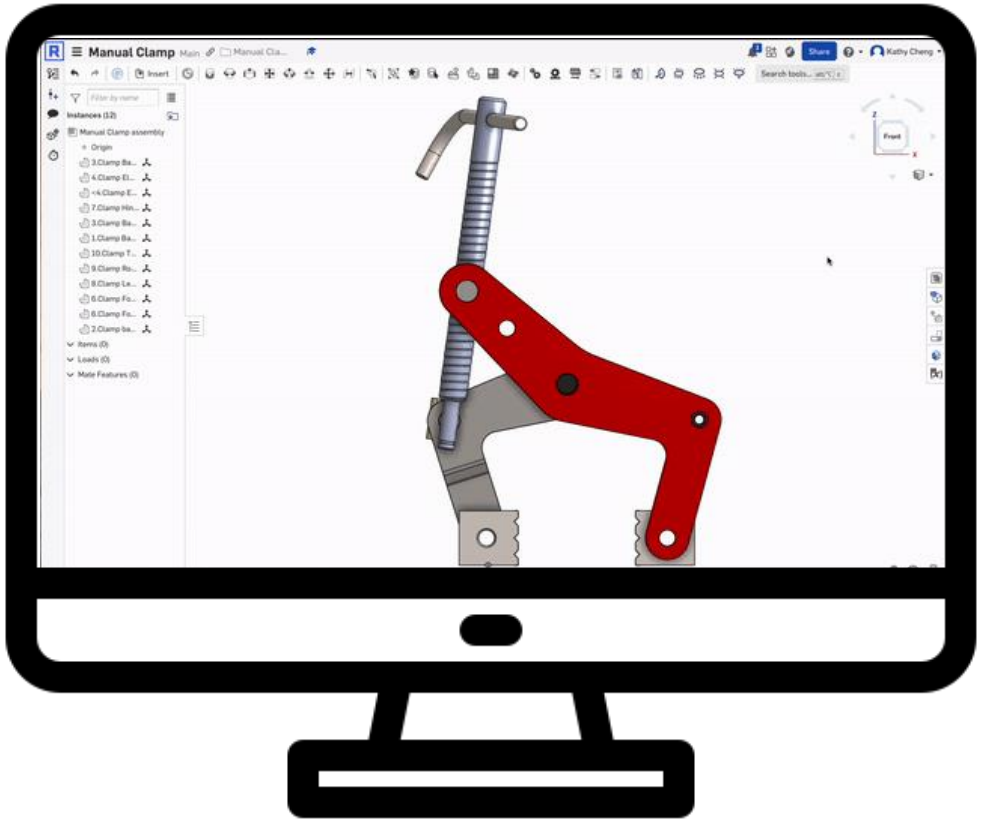


Occurs when multiple designers must coordinate and work together on CAD models. Challenges can result in designers making conflicting edits, overwriting each other's work, or creating duplicate work.

Challenge: Designers use varied modelling conventions

"[Ideally,] the model should basically assemble itself and everything should be in the right place. If [designers] follow different conventions, the parts will just be flying off into space."

– P2



Challenge: Designers use varied modelling conventions

Workaround: Impose standards and best practices

"[Ideally,] the model should basically assemble itself and everything should be in the right place. If [designers] follow different conventions, the parts will just be flying off into space."

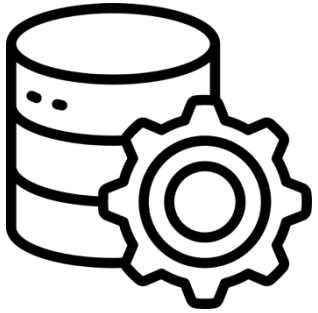
– P2

"We made two documents for standardizing the procedure, and then we gave it to all new designers who are coming into the company. It cannot happen overnight; it took 2-3 years to [bear] fruits, but afterwards everybody was modelling in the same way."

– P10

Data Management

- un-interoperability between systems
- lack of change summarization
- lack of version control for non-PLM
- poor organization of multi-use models
- scattered file management

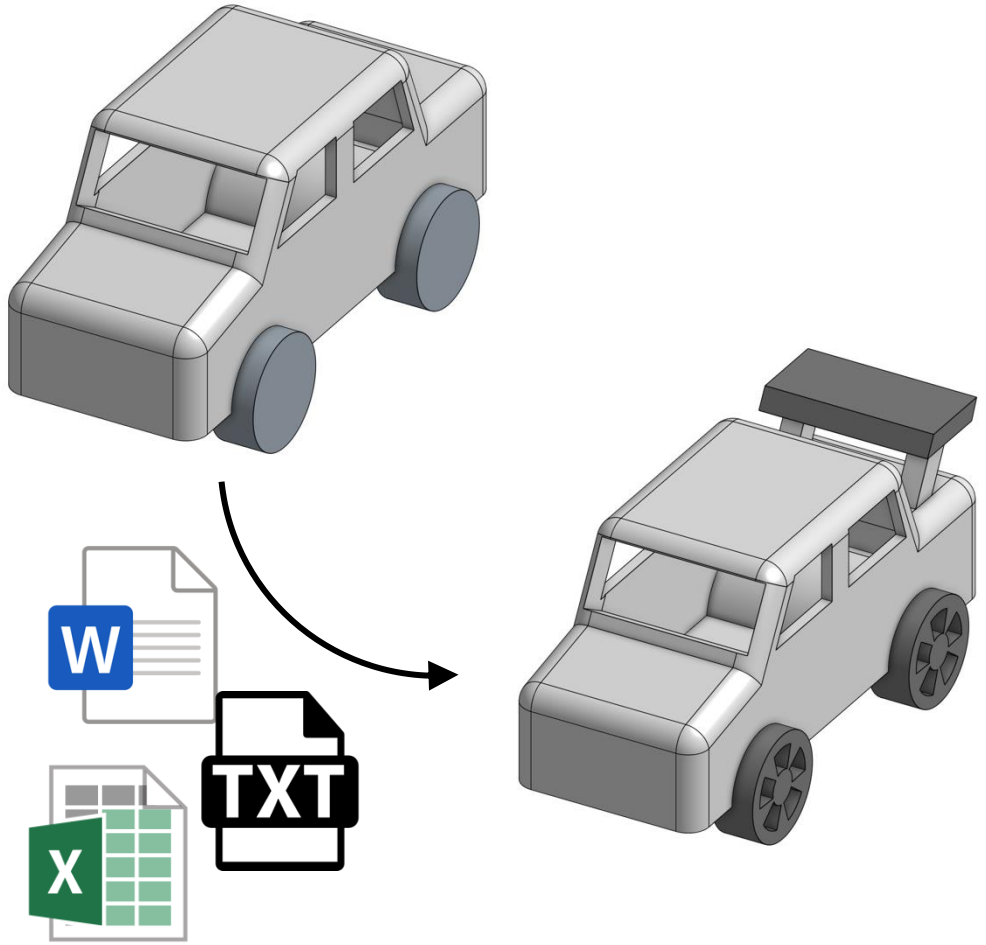


Occurs when designers have issues with storing and retrieving shared files, file versions, and file dependencies.

Challenge: Lack of change summarization between file versions

"The hardest thing with going back to a previous [model] version is keeping track of what you actually changed in each version. Usually, I'll [manually] make notes to say 'I edited these things,' but sometimes you change a lot of stuff, and you don't track everything."

– P18



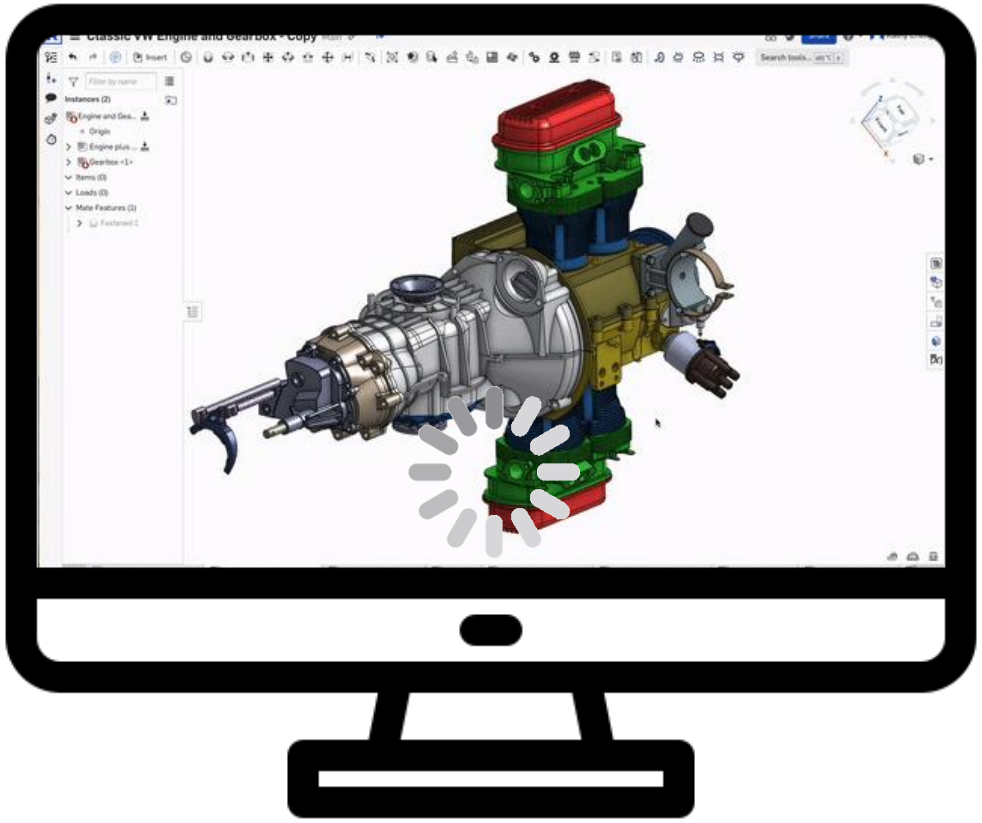
Synchronous Communication

- cumbersome model presentation
- lack of conceptual design support

Occurs when designers face difficulties conveying and discussing the contents and intent of CAD models during synchronous meetings

Challenge: Cumbersome model presentation in synchronous sessions

“Even though [the designer] is the most familiar with the design, so it should be easier to navigate the model, it is ultimately always really clunky and slow to hide all of the parts and find the right position.”
– P16



Thematic mapping of challenges

Collaborative Design	Data Management	Synchronous Communication	Permissioning
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infrequent model uploads	lack of change summarization	lack of conceptual design support	lack of access to CAD software
lack of awareness of dependencies	lack of version control for non-PLM		
lack of awareness of model changes	scattered file management		
lack of synchronous editing support	poor organization of multi-use models		

Future directions for addressing challenges

Better Tooling Support

- lack of awareness of dependencies
- un-interoperability between systems
- lack of awareness of model changes
- lack of change summarization
- lack of synchronous editing support
- lack of version control for non-PLM
- cumbersome model presentation
- poor organization of multi-use models
- lack of conceptual design support
- scattered file management

Unified Best Practices

- varied modelling conventions
- infrequent model uploads

Better Management

- cumbersome access to CAD files
- lack of access to CAD software

Future directions for addressing challenges

Better Tooling Support

lack of awareness of dependencies	un-interoperability between systems
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CAD **tool builders** can target:

- improving designer awareness
- facilitating traceability of documentation
- supporting file dependency management

Future directions for addressing challenges

Unified Best Practices

varied modelling conventions

infrequent model uploads

CAD **researchers/practitioners** can:

- develop best practices
- formally enforce and continually train best practices

Future directions for addressing challenges

CAD team **managers** can:

- proactively handle permissioning needs
- aid in enforcing CAD best practices

Better Management

cumbersome access to CAD files

lack of access to CAD software

Our work contributes a systematic classification of CAD collaboration challenges

Collaborative design and data management are the most pervasive challenges faced by professional CAD teams.

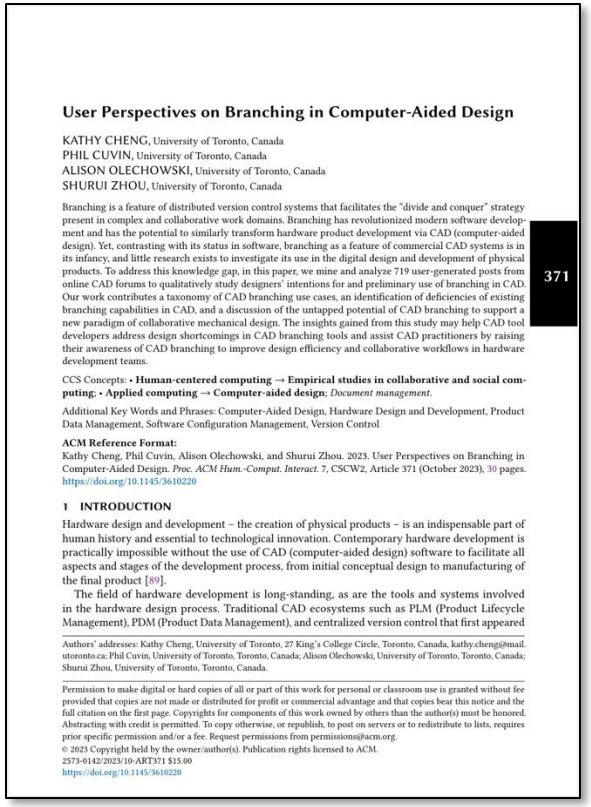
Some interviewees have developed workarounds, but they are insufficient to resolve all challenges.

We propose future directions towards tooling support, management, and best practices.

Future work aims to improve CAD collaboration

Better Tooling Support

User Perspectives on Branching in Computer-Aided Design



User Perspectives on Branching in Computer-Aided Design

KATHY CHENG, University of Toronto, Canada
PHIL CUVIN, University of Toronto, Canada
ALISON OLECHOWSKI, University of Toronto, Canada
SHURUI ZHOU, University of Toronto, Canada

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Branching is a feature of distributed version control systems that facilitates the "divide and conquer" strategy present in complex and collaborative work domains. Branching has revolutionized modern software development and has the potential to similarly transform hardware product development via CAD (computer-aided design). Yet, contrasting with its status in software, branching as a feature of commercial CAD systems is in its infancy, and little research exists to investigate its use in the digital design and development of physical products. To address this knowledge gap, in this paper, we mine and analyze 719 user-generated posts from online CAD forums to qualitatively study designers' intentions for and preliminary use of branching in CAD. Our work contributes a taxonomy of CAD branching use cases, an identification of deficiencies of existing branching capabilities in CAD, and a discussion of the untapped potential of CAD branching to support a new paradigm of collaborative mechanical design. The insights gained from this study may help CAD tool developers address design shortcomings in CAD branching tools and assist CAD practitioners by raising their awareness of CAD branching to improve design efficiency and collaborative workflows in hardware development teams.

CCS Concepts: • **Human-centered computing** → **Empirical studies in collaborative and social computing**; • **Applied computing** → **Computer-aided design**; *Document management*.

Additional Key Words and Phrases: Computer-Aided Design, Hardware Design and Development, Product Data Management, Software Configuration Management, Version Control

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https://doi.org/10.1145/3610220

1 INTRODUCTION

Hardware design and development – the creation of physical products – is an indispensable part of human history and essential to technological innovation. Contemporary hardware development is practically impossible without the use of CAD (computer-aided design) software to facilitate all aspects and stages of the development process, from initial conceptual design to manufacturing of the final product [89].

The field of hardware development is long-standing, as are the tools and systems involved in the hardware design process. Traditional CAD ecosystems such as PLM (Product Lifecycle Management), PDM (Product Data Management), and centralized version control that first appeared

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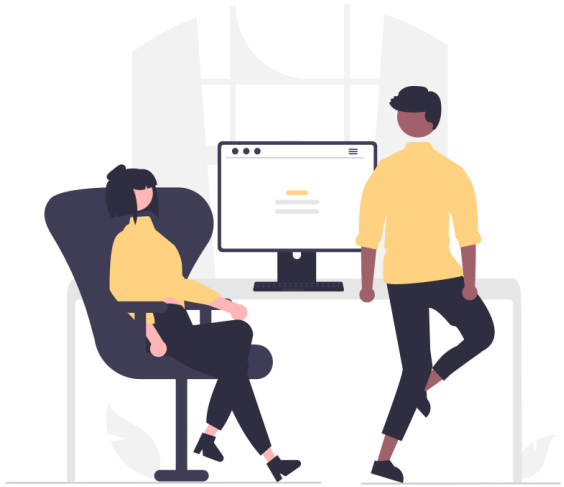
https://doi.org/10.1145/3610220

Unified Best Practices

Analyzing CAD trace data and interviews from a real industry design team



Thanks! Questions?

RQ1: What collaboration challenges do CAD designers face?

RQ2: What workarounds do CAD professionals use?

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FACULTY OF APPLIED SCIENCE & ENGINEERING

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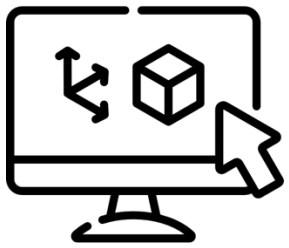
Three generations of CAD systems have emerged

1963

Standalone CAD:

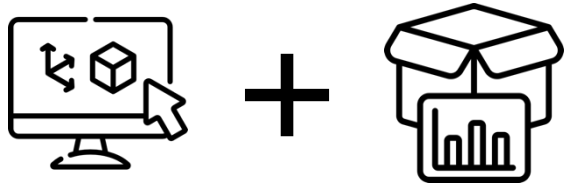
Interaction between a single user and a locally-installed CAD tool



1980s

Distributed CAD:

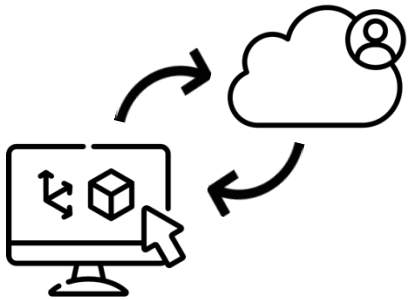
Product Lifecycle/Data Management (PLM/PDM) systems to enable collaboration



2010s

Collaborative CAD:

Supports cloud-based, multi-user, and synchronous collaboration

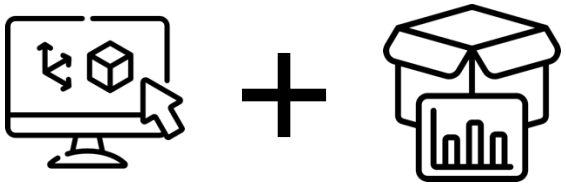


Sutherland (1964); Maher and Rutherford (1997); Fuh and Li (2005); Johnson (2010)

Despite being older, Distributed CAD still dominates

Distributed CAD:

Product Lifecycle/Data Management (PLM/PDM) systems to enable collaboration



Slow shift to cloud-based CAD
(especially among professional designers)

Maher et al. (2017); Warfield (2021)