1. Introduction

Computer-Aided Design (CAD) collaboration has been studied since the early days of CAD research, but standardized metrics and experimental procedures for synchronous, collaborative CAD research are lacking in the literature. In order to keep up with the increasingly rapid pace of innovation and consumer demand for customization, businesses must engage in global design chains and work collaboratively with partners both locally and overseas. This type of collaboration allows companies to gain a competitive edge by leveraging the strengths and expertise of different team members and partners in diverse locations. As the world becomes more interconnected, the ability to collaborate effectively across distances and cultural barriers becomes increasingly important for companies seeking to succeed in today's fast-paced marketplace. [2] In modern product design, manufacturing, and analysis, there is a growing need for collaboration in distributed environments. This collaboration is essential both technically and commercially, and it is critical to develop new collaborative design tools or update traditional standalone CAD systems to become collaboration native. With the increasing complexity of products, it is necessary to involve a team of experts with different specializations, and collaboration tools can facilitate communication, increase productivity, and reduce errors. [8] Additionally, as the Covid-19 pandemic spread rapidly across the globe in 2020 and 2021, CAD design collaboration became more important than ever in the industry. With team members working from various locations, the process of checking CAD designs in and out of production data management systems has become more complex. This has further amplified the typical issues that arise with production data management, such as version control and collaboration, making it even more critical to develop effective strategies for managing CAD files remotely. As a result, there is a growing need for innovative solutions that can help teams efficiently manage their design files and collaborate effectively, regardless of their location. [10] Our motivating paper is from Cheng et al. [3] which identifies challenges associated with distributed Computer-Aided Design (CAD) practice. One of the challenges is a lack of change summarization support between file versions. Teams currently rely on their memory or tedious Excel spreadsheets to capture changes between different versions of CAD files, which is time-consuming and prone to errors. Collaborating on CAD design is essential to effective product development. Facilitating the team to work together increases checkpoints, provides unbiased feedback and reviews, and adds complementary expertise to optimize the final production part.

Our report explores the challenges associated with distributed Computer-Aided Design (CAD) practice and investigates whether visualizations of Boolean differences can summarize changes between CAD file versions. Our report proposes two experiments to test the effectiveness of Boolean differences in summarizing changes. The first experiment involves timed cherry-picking tasks where participants are divided into two groups, one with access to Boolean differences between CAD file versions and the other without. The second experiment involves summarization tasks where participants are again divided into two groups, one with access to Boolean differences and the other without. Our report highlights the importance of this research in providing a faster and more accurate alternative to the current methods used to capture CAD file changes, as well as contributing to the development of techniques and tools for visualizing differences between complex files. Our report also acknowledges the challenges associated with the lack of standardization and the difficulty in interpreting visual differences from Boolean differences for some types of changes. Finally, our report predicts that Boolean differences will facilitate the reversing process significantly in the cherry-picking experiment and help users better summarize changes in the summarization experiment.

1. RQ

In this report, we present a mixed method to answer exploratory research questions (RQ) about collaborative CAD. In particular, we are interested in the following:

RQ: Do visualizations of Boolean differences summarize changes between CAD file versions?

The main objective of this research is to evaluate whether Boolean differences can effectively summarize changes between Computer-Aided Design (CAD) file versions. Boolean differences are a visualization technique inspired by git diff and 3D art workflows that can be applied to 3D solids to create new solids. By investigating whether these new solids can help designers understand changes between versions of CAD files, this research aims to provide a faster and more accurate alternative to the current methods used to capture CAD file changes. Moreover, this study aims to contribute to the development of techniques and tools for visualizing differences between complex files, which can have implications for other domains where changes in complex files should be summarized. The importance of this research lies in the fact that it can help CAD users identify and track changes between versions of files more efficiently. This, in turn, can lead to faster and more accurate design iterations, ultimately resulting in better-designed products. Additionally, this research can help advance the field of visualization by developing new techniques and tools for visualizing differences between complex files. Such tools can be useful in various domains, including engineering, architecture, and graphic design.

1. Background
   1. CAD

CAD or computer-aided design refers to the use of computer software to create, modify, and optimize design processes. It has revolutionized the way engineers and designers work by simplifying the design process and increasing the accuracy and precision of designs. CAD software can create both 2D drawings and 3D models, enabling designers to create complex designs with ease. The use of CAD can help streamline the designer's workflow, leading to increased productivity and faster turnaround times. Additionally, CAD can improve the quality and level of detail in the design, making it easier to communicate with stakeholders, clients, and manufacturers. It can also contribute to a manufacturing design database, allowing for the creation of future designs that can be built upon existing ones. CAD software is utilized to create electronic files that are then utilized for various manufacturing procedures. CAD is typically utilized together with digital production techniques. CAD/CAM software is utilized to develop items such as electronic circuit boards for use in computers and other devices. These software tools allow for more precise designs, faster manufacturing processes, and increased efficiency in the production of products. By streamlining the design and manufacturing process, CAD software has become an essential tool for many industries, including architecture, engineering, and product design. [1]

* 1. OpenSCAD

OpenSCAD is a software program for solid modeling that is script-based, free, and open-source. With OpenSCAD, 3D digital designs can be created easily and quickly by manipulating parametric variables that automatically adjust the entire part. This feature of OpenSCAD enables even those without extensive knowledge in 3D modeling to make simple modifications to existing designs. By using OpenSCAD, designers can save time and effort while producing accurate and detailed 3D designs. [4] The OpenSCAD program is used to create 3D models by defining geometric primitives and then modifying and combining them according to user-defined parameters. In this project, we chose to use OpenSCAD to create STL files for our dataset. By using OpenSCAD in this way, we were able to accurately compare the performance of different 3D printing methods and evaluate the effectiveness of their proposed techniques.

* 1. GIT

Git is a collaborative software platform that is predominantly used by programmers to manage changes to files. It enables multiple users to track changes, share and coordinate updates to those files. Although it is widely used by developers for source code management, Git could be used to manage and coordinate changes to files of any type. Git provides a system that enables developers to work together efficiently and effectively, making it a valuable tool for collaboration in software development projects. [5] The Git command "git diff" is a versatile tool that allows users to compare different versions of their Git data sources. By executing the diff function, users can quickly identify changes made between versions of their source code, documentation, or any other type of file stored in Git. [6] Git cherry-pick is a command in Git that allows users to pick any previous commit in a Git repository and apply it to the current working HEAD. This feature can be useful for selectively applying changes from one branch to another or reverting to an earlier state. By cherry-picking specific commits, users can undo changes or apply important bug fixes without having to merge entire branches. [7] The cherry-pick feature of Git can be helpful for undoing changes.

* 1. Boolean Difference

The use of Boolean operations, such as intersection, union, and difference, is vital in CAD/CAM systems. They help create complex geometric structures from simple building blocks, analyze spatial phenomena like interference, and model manufacturing processes such as machining. In order for these operations to be applied effectively in a CAD/CAM system, algorithms must be able to produce representations of geometric entities that are also closed under these operations. This ensures that the output from applying Boolean operations can also be used as input for subsequent operations. Therefore, it is crucial that the domain of a CAD/CAM system be algebraically closed under these operations. [9]

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