Title:
Developing a CAD Archetype Framework Based on User Data

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Introduction:

In the modern engineering environment, computer-aided design (CAD) is indispensable, enabling the virtual creation of parts and assemblies before physical prototyping [1]. As CAD evolves, it is increasingly important to facilitate collaboration, using multi-user CAD (MUCAD) programs and making the process more team-based and efficient [2]. MUCAD presents the possibility of synchronous collaboration in CAD, akin to working in "Google Docs", enabling multiple users to edit the same file simultaneously.

In 2021, Deng et al. proposed a framework for exploring MUCAD that established the various actions that are involved in a collaborative CAD workflow [3]. As MUCAD becomes more prevalent in engineering, understanding the way that teams interact grows more important [4]. By understanding user interactions within MUCAD software, insights may be gained on what separates high-performing teams from others, or how individual users typically work in large CAD design teams.

Understanding individual personalities is crucial for comprehending team dynamics, as the composition of personality types can significantly impact team success or failure [5]. Just as individual personalities influence collaboration and communication in generic teamwork environments [5], understanding how "CAD Archetypes" (CADA) may affect collaboration in MUCAD is key to fully comprehending how teams work best in the new realm of collaborative CAD [6]. Traditionally, personalities are analysed based on the "five-factor model" (FFM), which decomposes an individual's personality into five main factors: extroversion, agreeableness, conscientiousness, neuroticism and openness to experience [7]. These factors were selected based on their stability across user groups and extensive experimental validation, establishing them as fundamental components for classifying human personalities [7].

Our goal is to develop a framework similar to the FFM suitable for analysing MUCAD data and extracting CAD archetypes for CAD software users. We contribute a set of "classes" with multiple "dimensions" which when combined, will form the basis of defining a user's CADA. Developing a CADA can help future design teams better identify their strengths and weaknesses, increase design process efficiency, and maximize the potential for CAD user performance optimization.

Current State of MUCAD and Need for Collaborative CAD:

The concept of MUCAD is not new, dating back to as early as 1995 when Rutherford highlighted the necessity for a collaborative design environment where designs could be jointly worked on and visualized [8]. Chen et al. advanced this concept by proposing MUCAD as "the next generation CAD system" through their development of a cloud-based collaborative design system [4]. As technology has evolved through the years, modern cloud computing and computing power have improved significantly, paving the way for MUCAD, described as a "state-of-the-art evolution in CAD design" [3]. This evolution has led to increased collaborative potential in MUCAD systems, enabling synchronous work and unlocking numerous possibilities for real-time collaboration among multiple engineers [9].

Personalities in "Traditional" Psychology:

Individual personalities within teams can impact collaboration effectiveness [5]. As mentioned previously, personalities are typically based on the FFM from psychology, which classifies individual behaviour on five different factors [7]. The FFM has been widely studied in the field of psychology and deemed robust after multiple studies [7], attributed to the consistency of the model across user groups; regardless of the age, race, or geographical location of the group analysed, the same five traits consistently appeared across all groups studied [7]. The current gap in knowledge stems from the lack of a similar framework for analysing CAD user archetypes. By filling this gap, it will help engineering leadership and design managers to improve the CAD workflow and increase productivity by better understanding user behaviour.

Related Work and Other Explorations of CADA:

Several prior studies have explored CAD archetypes and user typologies. In 2023, Celjak et al. identified distinct user archetypes, including "part specialists", "assembly specialists", and "versatile team members" who work in both part and assemblies [10]. The study relied on a single data set comprising 42 undergraduate students organized into 14 teams of three members each [10], within a short timeframe. Thus, the findings may not generalize to a wide range of team sizes, scenarios, and professional companies.

Ross-Howe and Olechowski also investigated "user typologies" using clustering on a single dataset [11]. They found five typologies, "integrator", "designer", "facilitator", "constructor," and "resolver", where each typology performs different key events that contribute to their role classification. The user data originated from the "Robots to the Rescue" virtual design competition that was held in 2020, representative of 1140 users, across 146 teams, many of whom were high-school students [11]. Clustering analysis identified five main typologies; however, 520 of the 1140 users were categorised as inconclusive due to a lack of data [11].

In the following section, we discuss the development of a general CADA framework. The goal of our new CADA framework is to create replicable and robust results across diverse datasets.

Bottom Up "Archetype Dimension" Development:

The first step in this hybrid coding approach of CADA framework development is identifying all the typical actions that a CAD user may complete throughout a typical workflow. These standard CAD actions are listed in Table 1, based on the MUCAD framework developed by Deng et al. [3].

Table 1: Typical CAD User Actions by Category (adapted from Deng et al. [3]).

2D Sketching	3D Part Design	Assembly Mating	Browsing Models	Part/Model Management
Create a 2D Sketch	Extrude Sketch	Adding Parts to Assemblies	Renaming Features	Branching Model Version
Dimensioning Sketch	Cut Sketch	Deleting Assembly Parts	Add Comments	Merging Model Versions
Trimming Sketch Features	Loft Extrude	Adding Assembly Mates	Showing Parts	Renaming Versions
Undo Sketch Feature	Eng. Drawings	Deleting Assembly Mates	Hiding Parts	Version Documentation
Redo Sketch Feature	Undo Extrude	Redo Mate	Animating Parts	Deleting Model Versions
Copy Sketch	Redo Extrude	Undo Mate		

To develop the "CAD dimensions" upon which the classes are created, the list is analysed for actions which could be interpreted as contrasting variables that described the same general workflow (e.g. 2D sketching and 3D extrude actions both describe aspects of the modelling workflow), however, they are two different action types which contrast the actual working habits of the user. These groupings of two contrasting actions are those which can be separated into two polarising classifications that can separate user activity. For example, deleting mates compared to adding mates are two opposite actions.

There are other two-dimensional user dimensions which are less explicitly related to direct actions. An example of this can be seen in the dimension "additive vs subtractive" actions [12]. In these dimensions, the two sides of the dimensions are not intrinsically linked to individual actions; rather, there may be groups of multiple actions which map to the single dimension. In the case of additive vs subtractive actions, extrude, redo extrude, and loft extrude all map to additive actions on one side of the dimension, while the other side of the dimension (subtractive actions) only includes cut and undo extrude actions.

Based on the actions in Table 1, a list of dimensions is created and can be seen in Table 2. The metrics column proposes methods of calculating each dimension's "score". The list of dimensions was deemed "complete" once there was evidence of significant overlap between dimensions, thus making some of them redundant and eliminating the need for further dimensions to be added.

Table 2: CADA classes, dimensions, names, and measurement metrics.

Class	Dimension	2 Sides of Dimension	Metric (Actual Measure)
Collaboration	Document Creation	Starting New Documents vs Working on Existing Documents	New documents created divided by existing shared documents opened
	Contribution Level	High vs Low Contribution	Edit Qty divided by Team Average Edit Qty
	Document Ownership	Branching vs Merging Actions in Part Management	Branching actions divided by merge actions
Management	Viewing Frequency	Viewing vs Editing of Parts	Parts shown, animated, hidden divided by edits made
	In-CAD Observations	Number of Parts/Assemblies Viewed vs of Drawings and Other Documentation Viewed	Number of parts/assemblies viewed, divided by number of other documents opened
Structure/Order	Revision Ratio	Features Creation vs Revisions	Creation Actions divided by Edits/Deletions
	Design Intensity	Reflective vs Intensive Part Design	Number of edits divided by time period
	Documentation Level	Commenting and Renaming vs Edits Made	Number of edits divided by number of comments
Modelling Style	3D Modelling Style	Subtractive vs Additive Actions	Cut Actions divided by Extrudes
	Part/Assembly Ratio	Individual Part Design Quantity vs Assembly Mating	Parts edited divided by assembly mates made
	Feature Deletion	Creating New Part Features vs Deleting Part Features	Creation actions divided by deletions
	Net Part Ratio	Adding Parts to Assemblies vs Deleting Parts in Assemblies	Part additions divided by number of deletions
	2D/3D Ratio	2D Sketching vs 3D Part Design	2D sketches made divided by 3D features extruded/cut
	Session Length	Long Continuous Time Spans Working vs Shorter Sessions	Session length, from document open to close

<u>Bottom Up "Archetype Class" Development and Scoring:</u>

After identifying 14 different dimensions, similar dimensions were grouped together by inspection to create "classes" which, when combined, will form the basis of the CADA framework. We used axial coding to develop the dimensions; as more dimensions were added, clear groupings of dimensions naturally emerged by connecting similar concepts. These classes are similar to the factors in the FFM for "traditional" personality types but specific to a CAD context. These classes and their full list of classification dimensions are summarised in Table 2. The four primary classes that emerged are:

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- Collaboration Level - Summarises how much users work with others compared to individually.
- Modelling Style - Summarises the user modelling-related actions in a typical CAD workflow.
- Management Level - Provides insight into the bureaucratic level of users within the CAD team.
- Structure and Order Level - Summarises the structure/order of a user's CAD workflows.

The "modelling style" class contains twice as many dimensions. Thus, this class will be multi-dimensional, combining to form a more complex class that is not only bilaterally rated but will be represented by a radar chart. The proposed method of scoring each class is taking the averages of all dimensions for a given class. For example, in the collaborative level class, first calculate the ratios of document creation, contribution level and document ownership. Once these ratios are all calculated for one user, summing all these values will yield a final "class" score for each individual.

To compare class scores between individuals, the average of all users' class scores can be taken, and then individual users can be compared to this average. For example, each class (collaborative, management, structure/order) has an average score across all users. Then, to classify individual users' relative position in each class, their individual scores are compared to the average of each class.

Top Down "CADA Class" Comprehensiveness Analysis:

To develop the CADA framework, first it was determined that there were limited additional dimensions which could be developed without significant overlap. From the list of already existing dimensions, groups were formed by axial coding, and thus the list of four classes were formed. In this next stage of analysis, the classes are evaluated for completeness and thoroughness using a top-down approach, which studies the classes themselves and potential gaps, rather than developing classes from dimensions.

Using this top-down approach, the four existing classes are analysed and compared to the FFM in traditional psychology. The FFM is robust because of its consistency across various groups and over time, the full spectrum of each factor is covered, and not all individuals rank consistently on one side of the scales. The proposed CADA framework lists classes that should theoretically satisfy two of the three points listed; with (1) the full spectrum of each CADA class being used, and (2) not all users ranking consistently the same across CADA classes. The classes selected should separate users, as not everyone will be the same level of collaboration or management and there should be users across the full spectrum of these classes from senior managers to junior engineers.

By analysing all the potential CAD workflow actions as well as reading related literature, it is determined that there are not any gaps in classification that must be covered. Later analysis and applications to case studies may show that there exist gaps in the framework, however thus far there is no clear need for additional classes for completeness of the CADA portfolio.

Summary of CADA Framework Development:

First, a list of CAD actions is laid out based on previous studies in MUCAD. This is followed by an intentional selection process to identify two-sided dimensions that form the basis for "Archetype classes". These classes are groupings of dimensions that provide similar insights and are grouped by inspection. Below, the framework is summarised in a single table, based on all the work previously discussed, for reference and application to case studies in future work.

Conclusions and Future Work:

As MUCAD becomes more prevalent in modern engineering, understanding user interaction becomes more important to increase efficiency in CAD workflows. In this paper, we developed a CADA framework, aiming to categorize user archetypes, akin to psychology's FFM. Future research will involve testing the framework's effectiveness through case studies and applying the framework to CAD user data. By taking professional user data and using the framework ratios to calculate user dimensions, the case study efficacy may be investigated; in this extended abstract the case study is omitted for brevity.

Table 3: Summary of final CAD archetype framework.

Class	Summary	Insight	Measures
Collaboration	Does this user tend to work more with others or alone?	Higher values indicate more collaborative tendencies.	Document Creation; Contribution Level; Document Ownership
Management	How often is this user performing supervisory actions?	Higher values indicate more managerial behaviours.	Version Control; Viewing Frequency; In-CAD Observations
Structure/Order	For each user, how organised is their CAD workflow?	Lower values indicate a more organised workflow and better planning.	Design Intensity; Revision Ratio; Documentation Level
Modelling Style	What are the typical user habits when using CAD?	Analysing radar chart shapes will help compare user modelling styles.	3D Modelling Style; Part/Assembly Ratio; Feature Deletion; Net Part Ratio; 2D/3D Ratio; Session Length

References:

[1] Ameri, F.; Dutta, D.: Product Lifecycle Management: Closing the knowledge loops, Computer-Aided Design and Applications, 2(5), 2005, 577-590. https://doi.org/10.1080/16864360.2005.10738322

[2] Eves, K.; Salmon, J.; Olsen, J.; Fagergren, F.: A comparative analysis of computer-aided design team performance with collaboration software, Computer-Aided Design and Applications, 15(4), 2018, 476-487. https://doi.org/10.1080/16864360.2017.1419649

[3] Deng, Y.; Mueller, M.; Rogers, C.; Olechowski, A.: The multi-user computer-aided design collaborative learning framework, Advanced Engineering Informatics, 51, 2021. https://doi.org/10.1016/j.aei.2021.101446

[4] Chen, J. Y.; Ma, Y. S.; Wang, C. L.; Au, C. K.: Collaborative design environment with multiple CAD Systems, Computer-Aided Design and Applications, 2(1-4), 2005, 367-376. https://doi.org/10.1080/16864360.2005.10738385

[5] Juhász, M.; Influence of personality on teamwork behaviour and communication, Periodica Polytechnica Social and Management Sciences, 18(2), 2010, 63-77. https://doi.org/10.3311/pp.so.2010-2.02

[6] Leonardo, K.; Olechowski, A.: Identifying computer-aided design action types from professional user analytics data, ASME International Design Engineering Technical Conference, 2021. 2010, 63-77. https://doi.org/10.1115/detc2021-72102

[7] McCrae, R. R.; John, O. P.: An introduction to the five-factor model and its applications, Journal of Personality, 60(2), 1992, 175-215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x

[8] Rutherford, J.: A multi-user design workspace, Proceedings of the Sixth International Conference on Computer-Aided Architectural Design Futures, 1995, 673-685.

[9] Stone, B.; Salmon, J.; Eves, K.; Killian, M.; Wright, L.; Oldroyd, J.; Gorrell, S.; Richey, M. C.: A multi-user computer-aided design competition: Experimental findings and analysis of team-member dynamics, Journal of Computing and Information Science in Engineering, 17(3), 2017. https://doi.org/10.1115/1.4035674

[10] Celjak, R.; Horvat, N.; Škec, S.; Martinec, T.: Data-driven approach toward identifying CAD user archetypes, Computer-Aided Design, 2023, 302-306. https://doi.org/10.14733/cadconfp.2023.302-306

[11] Ross-Howe, A.; Olechowski, A.: Determining CAD Typologies from Onshape Audit Trails Using Clustering, Onshape Research Symposium, 2023.

[12] Velikonja, V.: Exploring the Presence and Cause of Manufacturing Fixation Design in Novice Mechanical Engineers, Undergraduate Thesis, University of Toronto, 2023.