

Towards Building an AI-Integrated Computer-Aided Design Platform for Design Research

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Project Objectives and Goals

- To develop a **fine-grained data-driven research platform** to support studies in engineering system design.
- To identify **beneficial design patterns** and aid designer grouping based on their sequential design behaviors.
- To **computationally model and predict** human sequential decisions using deep-learning methods.
- The **overall goal** of this project is to build an AI-integrated computer-aided design (CAD) tool for data-driven design research.

Background

- We transformed Energy3D, a solar system design software, to a research platform for data-driven design thinking studies [1].
- Energy3D has various unique features for system design research.

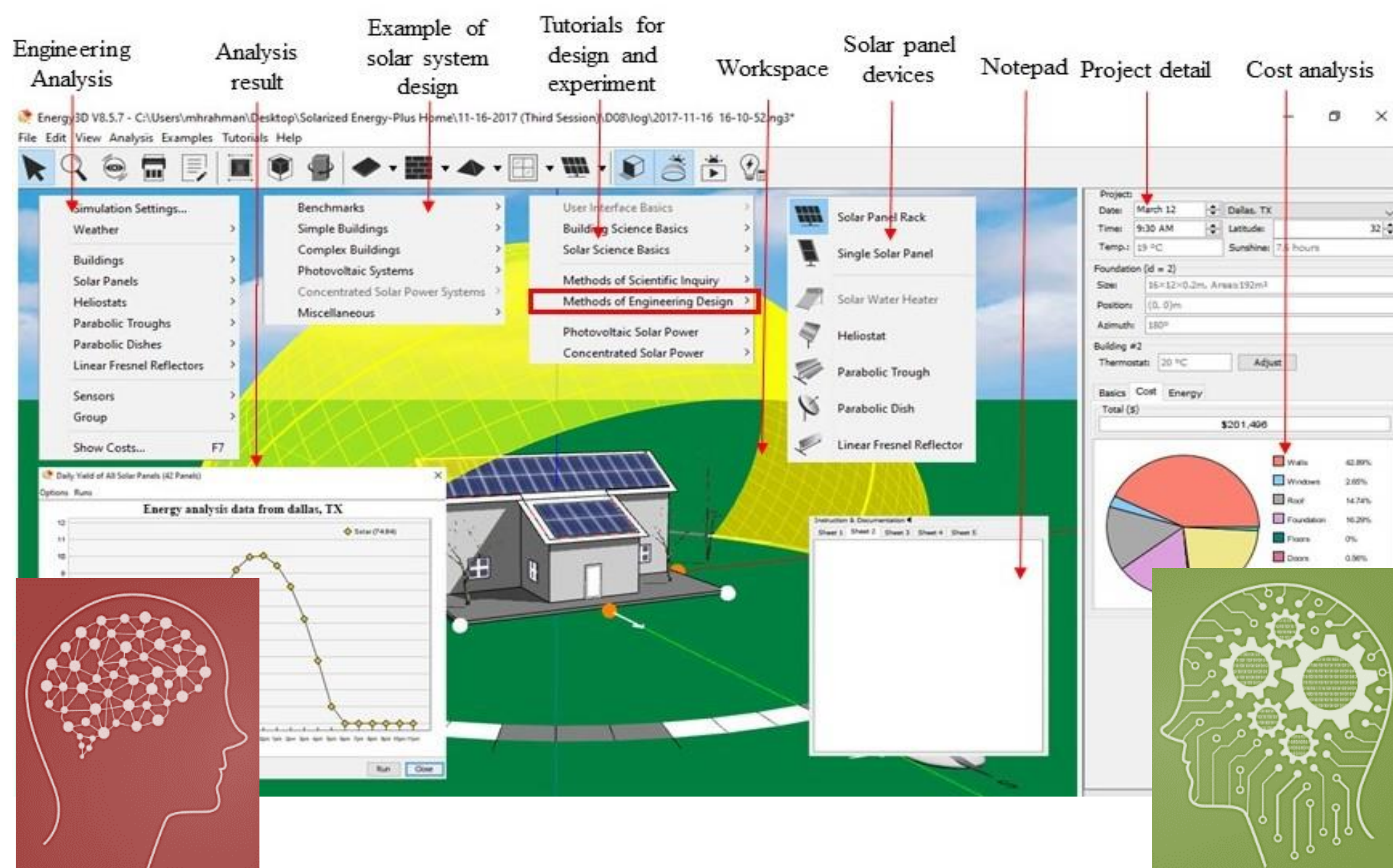
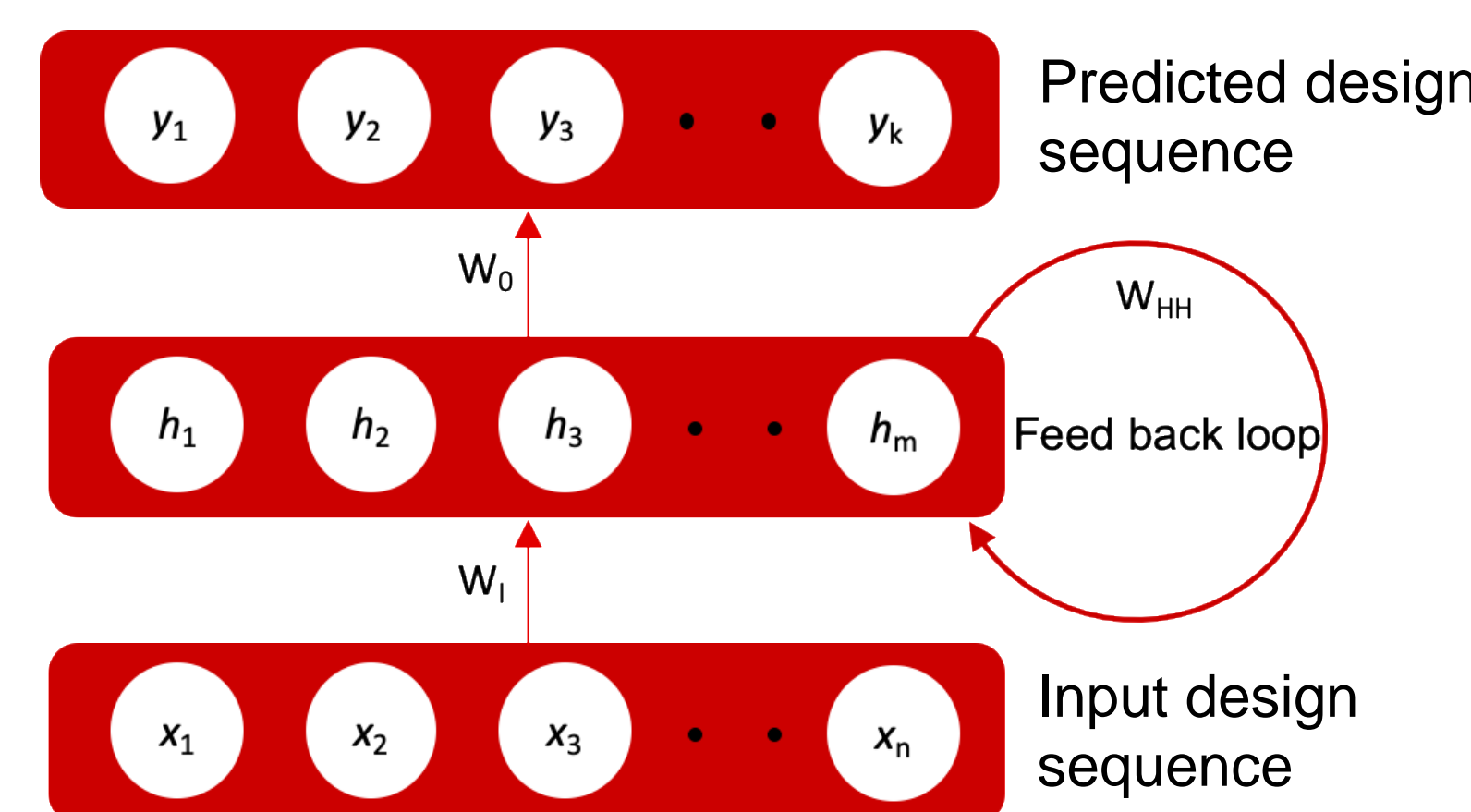
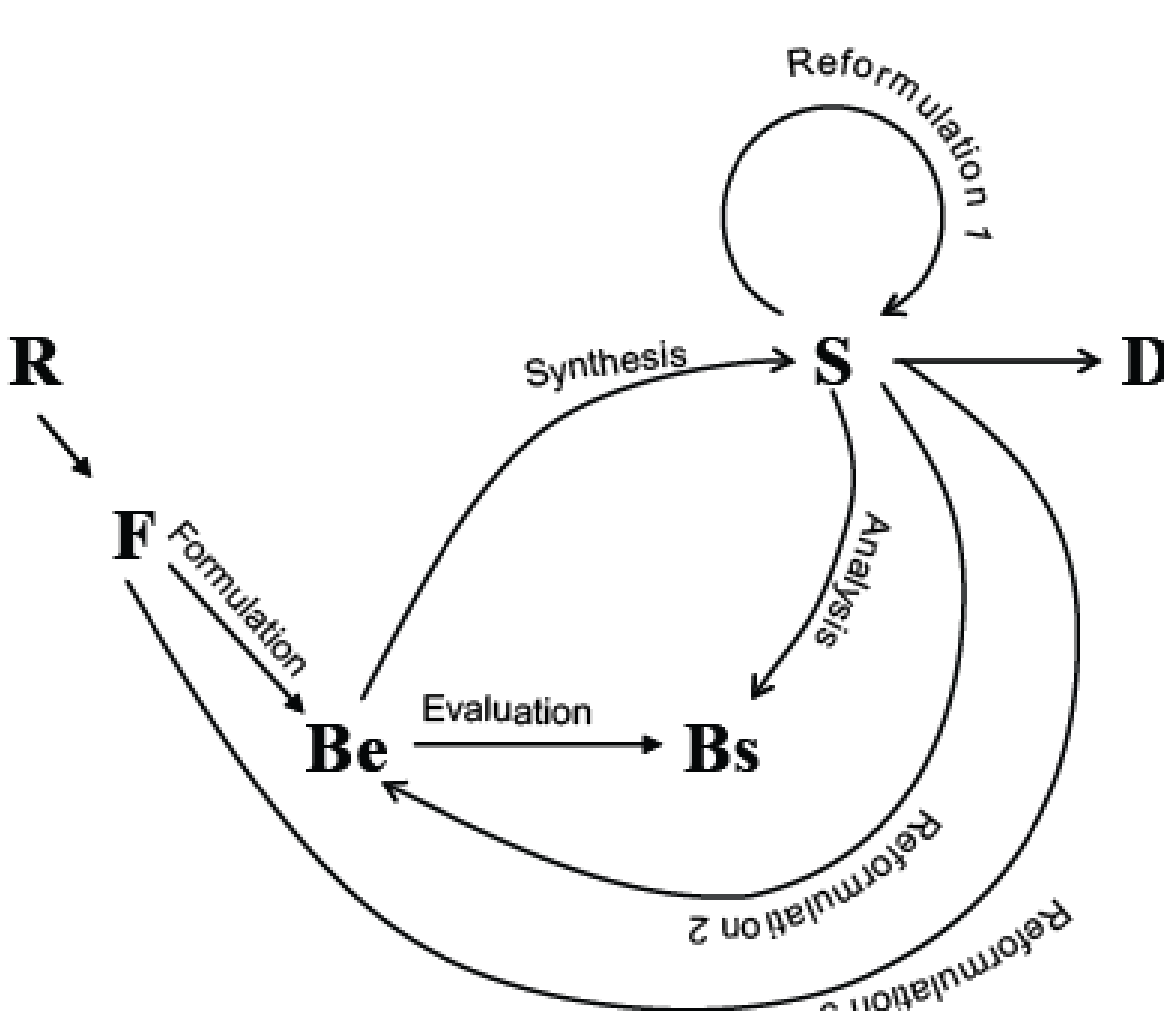


Figure 1: Build an AI-Integrated Design Tool

- Function-Behavior-Structure (FBS) based design process model is used to facilitate the abstraction and modeling of design thinking and help reduce the dimensionality in modeling.
- Unsupervised cluster algorithms are used to identify designers of similar sequential behavior [4].
- Deep-learning models, particularly the recurrent neural network and its variant long short-term memory unit (LSTM) and gated recurrent unit (GRU), are adopted to predict future design decisions.

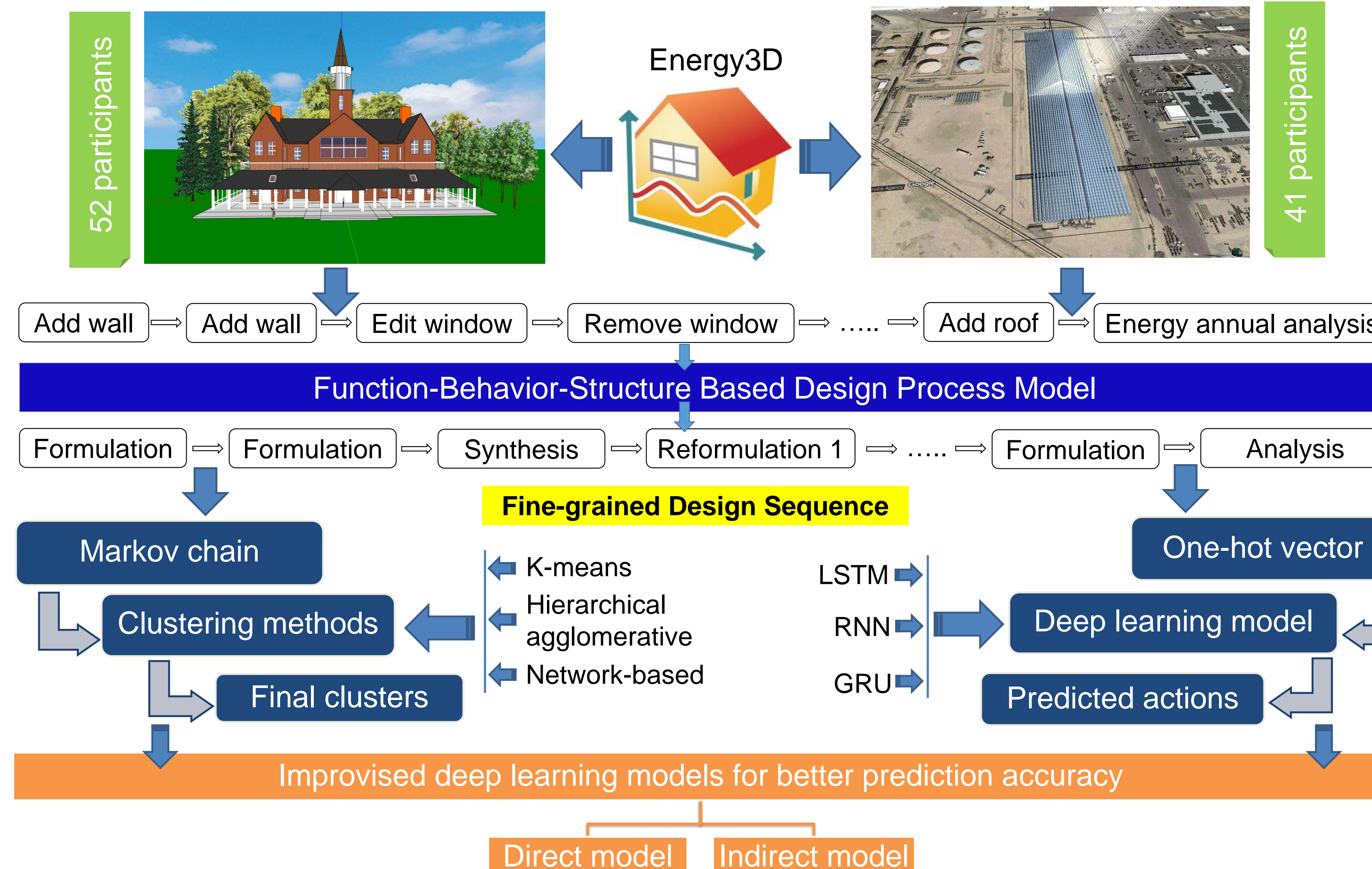


(a) Function-Behavior-Structure model [5] (b) Recurrent neural network [6]

Figure 2: Computational models used in this study

Experimental Setup

We conducted two design experiments: Energy-Plus Home Design and Solarized Parking Lot Design



Data and Results

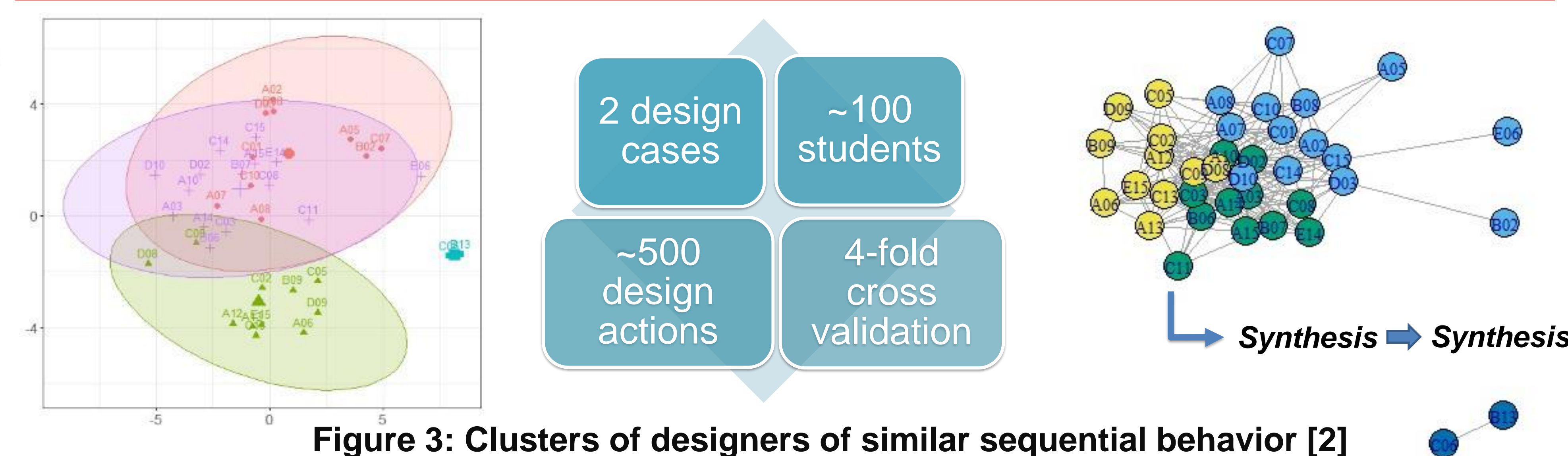


Figure 3: Clusters of designers of similar sequential behavior [2]

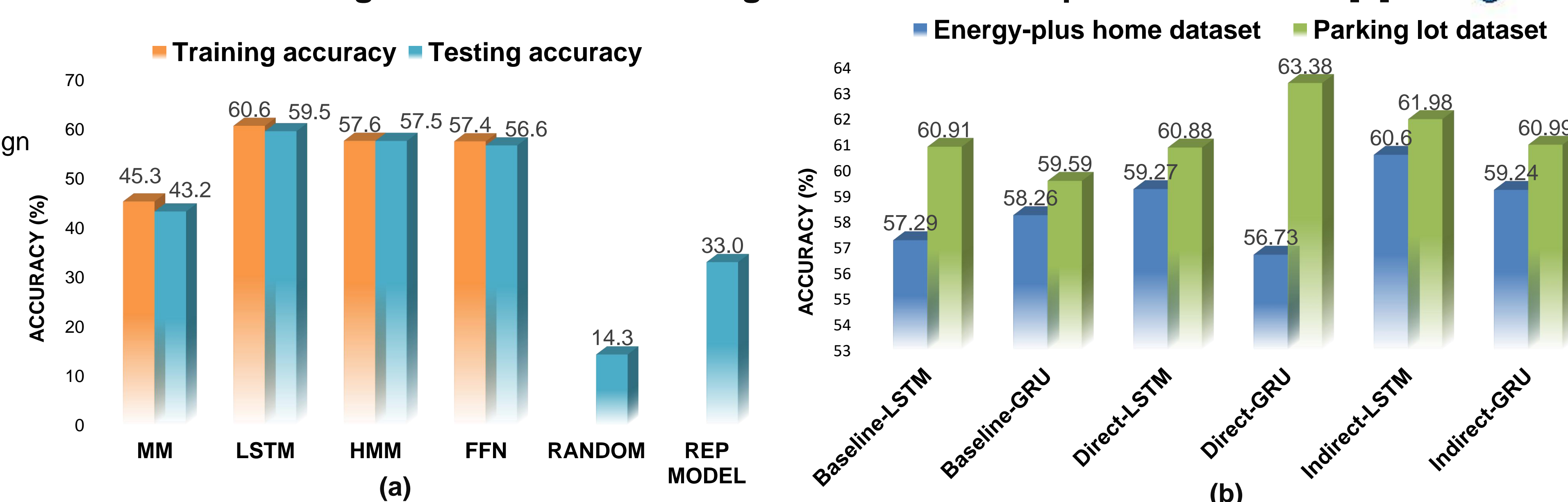


Figure 4 : a) Comparison between deep-learning models and traditionally used sequential models [3]
b) Comparison between improved deep-learning models and baseline models

Conclusions and Contributions

- We developed an open-source research platform that facilitates fine-grained data-driven design thinking studies based on Energy3D.
- We developed an approach based on Markov chain model and clustering algorithms to identify design patterns and designers of similar behaviors.
- We developed a deep-learning based approach that achieves higher prediction accuracy than the traditional sequential models, e.g., hidden Markov model and Markov chain model in design field.
- We improved our deep-learning models by integrating both human attributes and human design actions which shows promising prediction.
- In summary, this project lays a **stepping stone** towards building an AI-integrated computer-aided design platform for design research.

Future Work

- To develop a bi-level framework using **embedding technique** to predict human design actions based on the current model which predicts design processes.
- To integrate **system thinking factors** into the predictive models by extracting human psychological factors and cognitive skill.
- To implement **reinforcement learning**, such as Markov Decision Process (MDP), to further advance the artificial intelligence in our platform.

Publications

- [1] Rahman, M.H., et al. *Automatic Clustering of Sequential Design Behaviors*. in *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.
- [2] Rahman, M.H., Schimpf, C., Xie, C. and Sha, Z., 2019. A Computer-Aided Design Based Research Platform for Design Thinking Studies. *Journal of Mechanical Design*, 141(12).
- [3] Rahman M.H. et al. "A Deep learning-based Approach to predict sequential design decision", in *ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. (Robert E. Fulton Best Paper Award)

Acknowledgments

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References

- [1] P. Berkhin, "A survey of clustering data mining techniques," in *Grouping multidimensional data*: Springer, 2006, pp. 25-71.
- [2] Gero, J. S., 1990. "Design prototypes: a knowledge representation schema for design". *AI magazine*, 11(4), p. 26.
- [3] Goodfellow, I., Y. Bengio, and A. Courville, *Deep learning*. 2016: MIT press