TOWARDS CO-BUILD: AN ARCHITECTURE MACHINE FOR CO-CREATIVE FORM-MAKING

by

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ABSTRACT

MANOJ DESHPANDE. Towards co-build: an architecture machine for co-creative form-making. (Under the direction of PROF. ERIC SAUDA)

Based on Negroponte's idea of man-machine symbiosis, this thesis proposes: Co-Build - A real time web based collaborative 3D modelling platform. The aim of the study is to understand the symbiosis by extracting different circumstances under which contributions from co-creative agent (machine) appear to make sense. And by extracting different aspect of human - human collaboration that can be applied to human - machine collaboration.

The machine behavior is based on enactive model of co-creativity. For the purpose of the study, machine intelligence is emulated using the wizard of oz technique and the machine action is restricted to mimicking. To simplify the complexity involved in architectural design process, the study focuses on additive massing models, specifically in the context of concept design game which focuses on interaction namely, the silent game.

Further two variations of silent game namely, switch silent game and simultaneous silent game are proposed to test two kinds of interactions between the collaborators namely, turn-taking and simultaneous interactions. Further, the study reports the results of an online user study with 20 participants. The user study involves participants playing both the variation of silent games first with a human and then with the wizard of oz machine. Retrospective video walkthrough and post task interview are the methods utilized to collect data for evaluation.

DEDICATION

To my parents,

Mr. D.N. Suresh Kumar and Mrs. Divya Suresh

and my younger brother

Mukund Deshpande

ACKNOWLEDGEMENTS

At the very outset of this thesis report, I would like to extend my sincere and heartfelt gratitude to all the people who have helped me in this endeavour. Without their active guidance, support, encouragement and constructive criticism, I would not have completed this research endeavour.

I am extremely thankful and would like to express my gratitude towards my thesis advisor Prof. Eric Sauda, and my committee members Dr. Mary Lou Maher and Dr. Dimitris Papanikolaou for their valuable guidance, expert comments, feedback and support for completion of this research project.

I would also like to thank Alireza Karduni for always providing the support and valuable guidance at crucial junctures of the research. I would like to thank HCI lab memebers Jeba Rezwana and Sarah Abdellahi for helping me in narrowing down the research focus and for guiding me towards very helpful resources. I would also like to thank Lucas Majerowicz for his open source code on building real-time applications It is due to this awesome blog post and repository that I was able to make Co-Build, a crucial component for this thesis.

I also acknowledge with a deep sense of reverence, my gratitude towards my parents and my brother, who constantly supported me and motivated me to complete this thesis. I also extend my gratitude to my friends Parth Amrapurkar and Saloni Gupta, who proofread my document many times and provided support for completion of this work.

At last but not the least I thank all the participants who took part in the user study and provided their valuable feedback.

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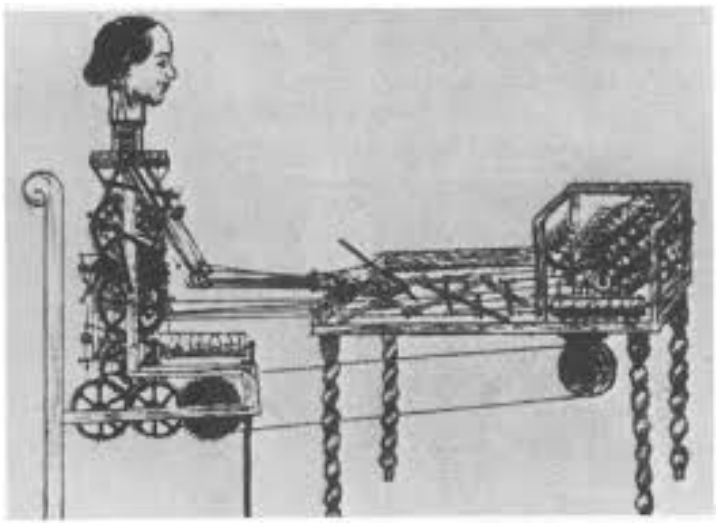

Figure 1.1: The Evolutionary Machine [Negroponte, 1969]

1.1 Architecture Machine

Nicolas Negroponte, one of the early pioneers of the infusion of the computer process to architecture. In his 1969 article "Towards a Humanism Through Machines", described the term "Architecture Machine" that referred to turning the design process into a dialogue that would alter the man-machine dynamic [Steenson, 2017]. Architecture machines are symbiotic in nature, and Negroponte defined symbiosis as "the intimate association of two dissimilar species (man and machine), two dissimilar processes (design and computation) and two intelligent systems (the architect and the architecture machine)" [Menges and Ahlquist, 2011]. By attributing architecture machine as intelligent, Negroponte envisioned the relationship between the architect and the architecture machine not as a master (smarter) and a slave (dumber), but to be a partnership of two associates with each having the potential of self-improvement.

But nearly after five decades and so many advancements in technology, even though designers can easily create and modify a CAD model, the CAD software largely functions as an input device. And even while the current fabrication/prototyping technologies and machines have led to a wealth of techniques to create physical artifacts of virtual objects, they largely function as output devices [Kim et al., 2017]. And as a result, machines are detached from the conception of design and Negroponte's man-machine symbiosis has not yet been achieved. To address this, I propose "co-build" an architecture machine - a partner to the designer.

1.2 Computational Co-Creativity

The notion of machines/computers as intelligent creative partners has been studied extensively in the emerging field of computational co-creativity. When computers and humans collaborate with each other to build a shared creative artifact, it is referred to as co-creative [Davis et al., 2015]. For the definition to be applied to this research, terms like "collaborate", "shared", "creative" and "artifact" need further contextual clarification (described in the sections below). For this thesis I will be utilizing the enactive model of creativity [Davis et al., 2016] to design co-build: the architecture machine. Within the theory of enaction I will be utilizing the conceptual framework of participatory sense-making to understand collaboration. I follow closely the design and evaluation frameworks and methodologies employed in the co-creative application - Drawing Apprentice.

1.3 Goals and Research Question

The following research goals:

- RG1:To understand/extract different circumstances under which contributions from machine - the co-creative agent appear to make-sense.
- RG2:To understand which method of interaction (simultaneous/turn-taking) promote good co-creative experience.

- RG3:To extract different aspect of human-human collaboration that can be applied to the human - machine collaboration.

The following are my research questions:

- RQ1:To what degree was participatory sense-making present during the collaboration (in both the the cases)?
- RQ2:What metrics and features did users employ to determine whether contributions from the machine 'made sense'?
- RQ3:Is the machine considered as collaborator or a tool?

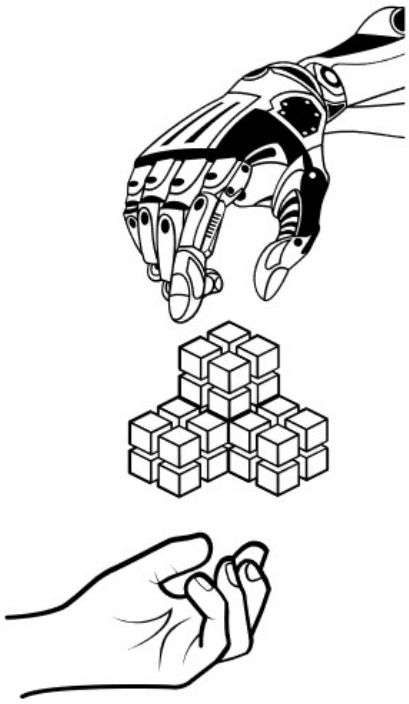

Figure 1.2: Co-Creating with the Architecture Machine

CHAPTER 2: CONTEXT AND THEORY

2.1 Architectural Massing Models

In the architectural discourse, physical/virtual models are exploratory design tools which allow architects to create rough abstract concepts, as well as to extract more detailed information for the later stages of their designs. For students and practitioners, testing digital findings with physical/virtual prototypes can be supportive for assessing if a complex solution is really offering "spatial, aesthetic and programmatic" solutions to a project. Therefore, each physical and digital phase of the project can inform each other subsequently and iteratively [Gulay and Lucero, 2019].

One of the early stages in an architecture design process is extensively making "massing models". Massing in architecture refers to the basic three-dimensional shape of the composition of the building [Thompson, 2012]. These models are quick first attempts to design how an architectural intervention looks. It can be used to study how the mass reacts to the site and context around it or it can be thought of as a site-less architectural form making. Francois Blanciak in his book Site-less provides an open-ended compendium of visual ideas for the architectural forms [Blanciak, 2008]. Since massing models are a simple three-dimensional composition, we can broadly divide the models into two categories subtractive models and additive models. Subtractive models are stereotomic in nature, that is they are carved out of a solid block, usually a foam block. Additive models are aggregative, that is small pieces or blocks are attached to form the massing. Massing models are usually small scaled but, have the potential to be of any scale. For example, Jennifer Bonner in her project domestic hats plays around with an awkward scale of the massing models of ordinary roof typologies and reconsiders their role in architectural representation [bonner, 2014].

Massing can also be sculptural which is explored in few of the student projects in exquisite corpses studio [Coersmeier, 2017]. For this study I will be utilizing additive 3D models.

Figure 2.1: (From left to right) Subtractive Massing [Architects, 2010], Domestic Hats [bonner, 2014], Exquisite Corpses Studio [Coersmeier, 2017]

2.2 Architectural Massing Design Games

Even though massing models are employed in early stages of design, the complexity and open-ended nature of the modelling process becomes a challenge to understand and to replicate while building an intelligent agent as a part of the architecture machine. To, reduce the complexity of task, I propose to utilize design games for this thesis. Also as Negroponte suggests, by utilizing games a machine's adroitness in design could evolve from local strategies that would self-improve by the machine testing for local successes and failures [Negroponte, 1975]. Design games are about staging participation, there is rarely any competition over who wins the game. In design games there are rules and tangible game pieces that guide the design moves [Vaajakallio and Mattelmaki, 2014]. Design games can be utilized to study design actions in a tractable environment that gives rise to design situations resembling those in real life. In games, as in real life, players' moves are limited by the existing rules, conventions and principles [Habraken and Gross, 1987]. There are various design games that have been developed for architecture and urban design, for example CLUG [Feldt, 1985] which is an acronym for community land use game, here multiple people collaborate in teams to move around physical 3D buildings of different

programs and typologies on a board. And as result of this game, different land use patterns of the city/district are explored and evaluated based on revenues/taxes each design iteration generates.

N. John Habraken and Mark D Gross in 1988 used games as a tool for research in design theory and developed nine concept design games. They suggest games provide an environment for a group of players, acting with individual goals and a shared program, to make and transform complex configurations, free of functional requirements [Habraken and Gross, 1987]. Concept design games represent theories about (aspects of) designing. By playing them, the theories are tested and most likely modified as a result. As indicated by the name each design game is based on a design concept. The concept that I am interested in exploring in this thesis is of - design interaction.

Habraken and Gross proposed nine concept design games, out of which two games are about design interaction - Reference Game and Silent Game. The Reference Game has a "Talker" who instruct the "Doer" as to what to do. The Talker may not move any pieces and Doer may not speak, message, draw or sketch, but only move pieces. The Talker gives a message to the Doer who interprets them in a configuration on the board. The Silent Game, in contrast, forbids any form of reference. The players are not allowed to talk. The first player lays out a pattern (made out predefined game pieces). Then the second player interprets the patterns adds another pattern to the configuration on the board for the first player to follow. An elaborate configuration emerges on the board representing a combination of patterns created by both the players. The sequence of game play is shown in fig 2.2. No explanation is given, nor are agreements formulated. Only the configuration is there. Action is all, and only medium available for communication is the set of pieces on the board. The silent game has two roles: pattern-maker and pattern-follower. Except the first and the last turns, each player plays both roles in each turn. The authors, to make the

game simpler propose, a protocol variation. Instead of playing both the roles of a pattern-maker and pattern-follower in each turn, one player can play exclusively as a pattern-maker and other player exclusively as pattern-follower. Although the Silent Game and the Reference Game represent very different modes of interaction, both show the importance of shared understandings/mental models in designing. Together they illustrate the extent to which interaction among designers is indeed rooted both in convention of seeing rules and goals in the deployment of pieces (in patterns), and in conventions of describing such deployments. For the purpose of this study, I will be employing two modified silent games "simultaneous silent game" and "switch silent game".

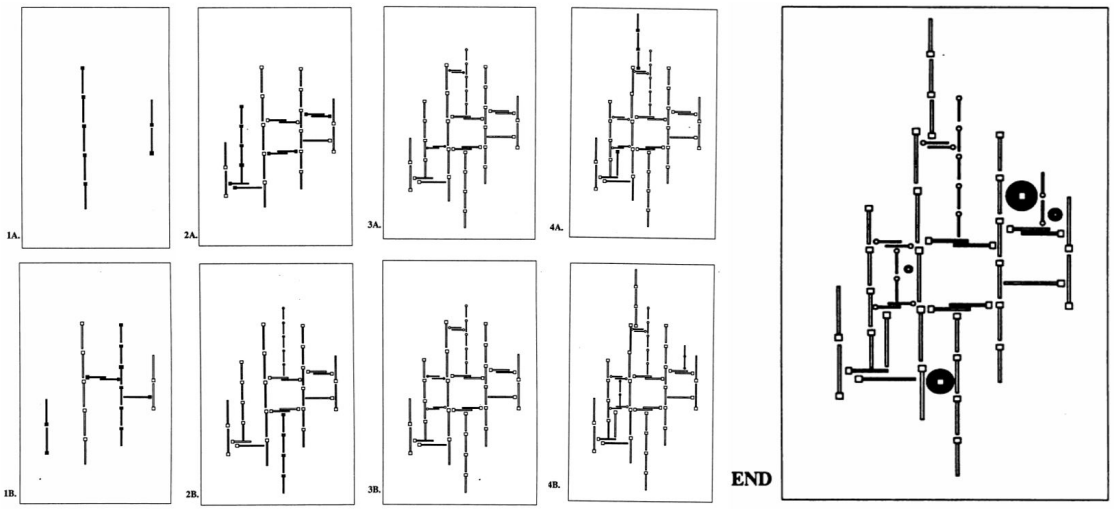

Figure 2.2: (From left to right) Example of turn-taking and game play during the Silent Game.

In both the games human collaborator will play as the pattern-maker and the software collaborator will play as the pattern-follower. The game will be played on a network based real time collaborative 3D modeling platform: "Co-Build" (for details refer the system design and interaction chapter). In the first game: "simultaneous silent game" after the first move by the pattern maker, both the pattern-maker and the pattern-follower will simultaneously add blocks to the 3D model, so shar-

ing/interaction is concurrent.In the second game "switch silent game" the pattern-maker and pattern-follower will be take turns and add blocks to the 3D model one after the other, so sharing/interaction is turn-taking.

To sum up going back to the definition of co-creative, the "artifact" in consideration is an additive 3D model resembling a simplified massing model - an open-ended spatial doodling. The "collaboration" is happening through design game on a web-based platform, the type of collaboration is mimicking. There are two types of "sharing" or interaction that are explored namely simultaneous and turn taking.

2.3 Enactive Model of Creativity

Creativity according to Webster's dictionary is the ability to create. Human creativity through the years has been studied through diverse perspectives such as philosophical, neuro-scientific, psychological, etc. In computational creativity literature, one of the dominant view on creativity is creativity as search [Wiggins, 2006] this approach assumes a potential solution space and it reduces creativity to searching the solution space to find the right fit for the given design problem . While this approach might be useful for optimization design problems in architecture, they are hardly of any help at the early/conceptual stage of design where the parameters are not set and there is no single "right fit".

One of the very prominent way of design thinking in architecture is "thinking by doing" it applies a wide range of activities like sketching, virtual or physical model making, engaging with a material, etc. The enactive model of creativity operationalizes "thinking by doing" method of cognition. As described in the paper "An Enactive Model of Creativity for Computational Collaboration and Co-creation", The enaction theory describes creativity as a continual process whereby cognitive agents adaptively and experimentally interact with their environment through a continuous perception-action feedback loop to produce structured, organized, and meaningful interactions in an emergent process of sense-making (or participatory sense-making when multiple

agents are collaborating). The emergent sensemaking process that results in creativity is fundamentally based on continuous real-time interaction between an agent and its environment [Davis et al., 2015].

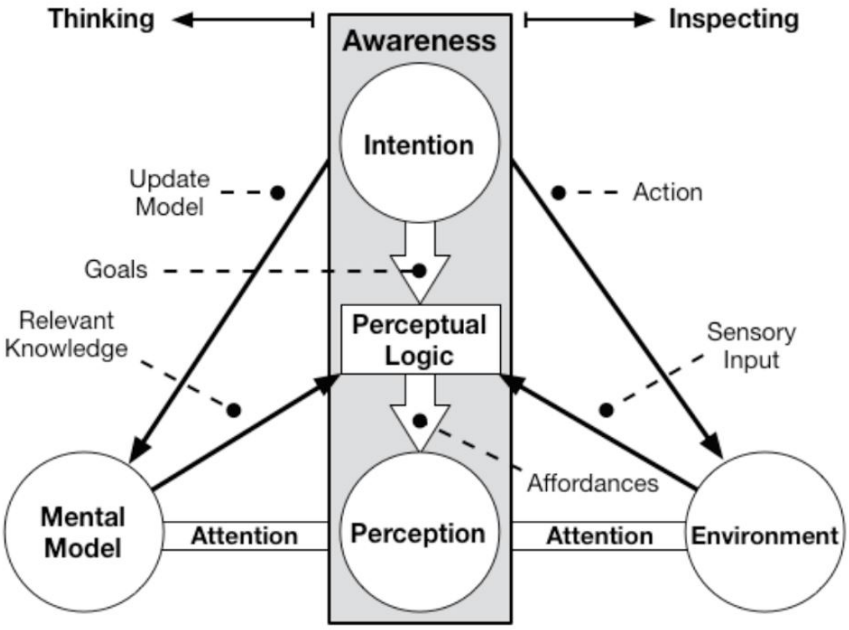

Figure 2.3: :Enactive model of Creativity [Davis et al., 2014]

The enactive model as shown in fig 2.3 is described as follows. The vertical rectangle represents agents the awareness, which means agent is aware of what is being perceived and what its intentions are. Perception of an agent is constituted by mental model - built from previous or similar experiences and sensory input from the environment. The awareness rectangle can shift to either left or right depending on the task being performed. For routine tasks the awareness rectangle is at the center. For new/unfamiliar task the awareness rectangle oscillates between right and left, that is agents actively take sensory information from engaging with the environment and build a mental model of the situation in a "perceive-think-act" cycle [Davis et al., 2014]. For simulating the intelligence in co-build I will be utilizing the enactive model of creativity.

2.4 Collaboration and Creativity

It has been established through various studies that creativity involves lateral thinking - the process of solving seemingly unsolvable problems or tackling nontrivial tasks through an indirect, non-linear, creative approach [Bono, 2010]. Also, all the design problems involve lateral thinking. Lateral thinking skills can be taught and by increasing it we can increase our creativity [Bono, 2010].One method of facilitating lateral thinking is by providing random stimulus [Beaney, 2005] - the introduction of a foreign conceptual element with the purpose of disrupting preconceived notions and habitual patterns of thought. And hence, collaboration (human-human) inherently provides this random stimulus and is an influential means to help designers push their creative boundaries and inspire their creative process [Davis et al., 2015]. In other words collaborators make complimentary and unexpected contributions; their shared product grows in an emergent manner that would be more creative than what each partner could achieve individually, this is termed as distributed creativity [Sawyer and DeZutter, 2009].

Various examples of collaborative creative works can be seen in various art movement in history one of the most relevant one is the “exquisite corpse”, in this each collaborator adds to a composition in sequence, either by following a rule or by being allowed to see only the end of what the previous person contributed. Analyzing it through the lens of co-creativity it can be said in exquisite corpse the artifact is painting/sketching, the collaboration is mimicking and interpretation, sharing is turn taking and even in this context the creativity can be explained through the theory of enaction. Even though the artifact is the painting/sketch it has no embedded meaning in it, it resembles a doodle or a collage. Similar to exquisite corpse co-build is to facilitate open ended collaborative 3D modelling like a 3D doodle.

CHAPTER 3: LITERATURE REVIEW

There have been various studies to show that human machine collaboration is achievable using simple set of algorithmic mechanism [Crandall et al., 2018]. But the kind of collaboration and authority/sharing varies. For this review, I have selected projects that are both software and fabrication architecture machines. In the HCI literature there are various frameworks for classification of co-creative systems both from human perspective and computational agent perspective. For this survey of related projects I will utilize the classification based on ideation described in the paper "Computational and Collective Creativity: Who's Being Creative?" [Maher, 2012]. Accordingly, computers can assume three roles namely support, enhance and generate. Computers in the support role provide the human with tools and techniques for supporting creativity. The computer as an enhancer extends the creative abilities of the human user by providing knowledge or encouraging creative cognition. Finally, the computer as a generator will provide the user with creative ideas to interpret, evaluate and integrate as creative products. Humans/users/designers on the other hand have two roles: to model and to generate. The first role describes a human who defines the computational models as processes of the computational agent, while in the second the human is facilitated or enhanced by a computer. [Kantosalo and Toivonen, 2016]. Although in majority of fabrication co-creative projects do not include any intelligent agent, I have still categorized them using this framework based on the seemingly intelligent mechanism they are built on.

Figure 3.1: Role of Computers in Co-Creation

In the first category, the computer or machine is just used as a tool and human is the creator or creative thinker. For example in projects like Interactive Fabrication [Willis et al., 2011] and Interactive Construction [Mueller et al., 2012], the human-machine collaboration for fabrication process is made easier with intuitive and embodied interaction with the fabrication machine (3D printer or laser cutting), these projects demonstrated how personalised artifacts can be created without loosing the designers intention. But, the fabrication machines just follow the instructions and have no creative control or feedback to the user. As a result these kinds of collaboration fabrication machines function as output devices and support the designers. Similarly projects like Protopiper [Agrawal et al., 2015] and D-Coil [Peng et al., 2015] allow users to extrude materials from a hand-held portable device to allow for real-time sketching on-the-go, sometimes in scale.

In the second category, machine with the help of a simple algorithm or with the help of AI acts like a creator. There have been various researches to show that computers with the help of AI can produce novel outputs that can be considered creative [Daniele and Song, 2019]. Projects like Being the Machine [Devendorf and Ryokai, 2015] and Crowdsourced Fabrication [Lafreniere et al., 2016], explore these kinds of collaboration. In Crowdsourced Fabrication users receive instructions on their smartwatch and they follow the instructions given by the machine to construct a pavilion module by module, in this scenario humans are used to perform tasks which a machine would require a lot of energy to do and as such humans have no input or control over the fabrication process. While in the Being the Machine, users receive step-by step G-code instruction from a machine, they are free to deviate and use their creative input while using a natural material to fabricate an object. In this project human body acts as mechanically controlled tool, trading precision and control with the ability to realize surprising and unexpected forms of artifact. While these projects foster collaboration between humans and machine, the role of the humans oscillate between

modeling and generating.

Co-creativite fabrication based projects that fall into the category of generate are FreeD, DeepWear,etc. in FreeD [Zoran et al., 2014] the author develops a milling tool which guides the user in this case artisan to create 3D models out of milling, the project is emergent as users are free to do as the please and the computer program adapts and sometimes redirects. Similarly in DeepWear [Kato et al., 2018] users or designers and AI co-create a new clothing by analysing fashion trends and production of single fashion brand. In Negotiating the Creative Space in Human-Robot Collaborative Design [Law et al., 2019] authors use a robotic arm along with a constrained tangible user interface that both the robot and humans can manipulate to create interesting arrangements in this project human designers have to negotiate both the physical and the creative space. In Truss Fab [Kovacs et al., 2017] system allows designers to fabricate large scale structures that are sturdy enough to carry human weight using plastic bottles. These bottles act like structural members. here the computer and designer co-create the artifact in the digital space and finally the assembly is carried out by the humans.

In past decades there have been a lot of HCI research and exploration in co-creative drawing/painting. For example in projects like I Lead, You Help but Only with Enough Details [Oh et al., 2018], Drawing Apprentice [Davis et al., 2015] and Relating Cognitive Models of Design Creativity to the Similarity of Sketches Generated by an AI Partner [Karimi et al., 2019] authors have explored and evaluted how AI driven systems can assist humans in drawing. Typically a user draws a line or a curve on the screen and depending on the AI implementation, computer extends and enchances this line drawing. Similarly in Computing with Watercolor Shapes [Gun, 2017] a custom drawing/painting apparatus is developed in which computer acts like a generative painting system and the designer traces and co-creates along with the computer. In all these projects the role of both human and computer is to generate and fall into

the third category.

In this thesis, I propose to create a co-creative software system similar to the various projects discussed above falling into the third category. To achieve this I plan to use web socket enabled web based platform where designers collaborate in a co-creative concept game play.

CHAPTER 4: SYSTEM DESIGN AND INTERACTION

The system is a network-based application called Co-Build which lets people collaborate in real-time to build 3D models on the web. The application uses Three.js (a JavaScript library and API) to create and display interactive 3D computer graphics in the web browser. Three.js uses WebGL to draw/render 3D objects. Broadly, the application consists of two parts a Node.js web server and a Three.js web client. The entire system design is shown in fig 4.2. The web server and web client communicate via WebSocket protocol. Co-build utilizes and builds on top of the Three.js voxel painter example [Cabello, 2019] and Lucas Majerowicz's code on building real-time applications [Majerowicz, 2020].

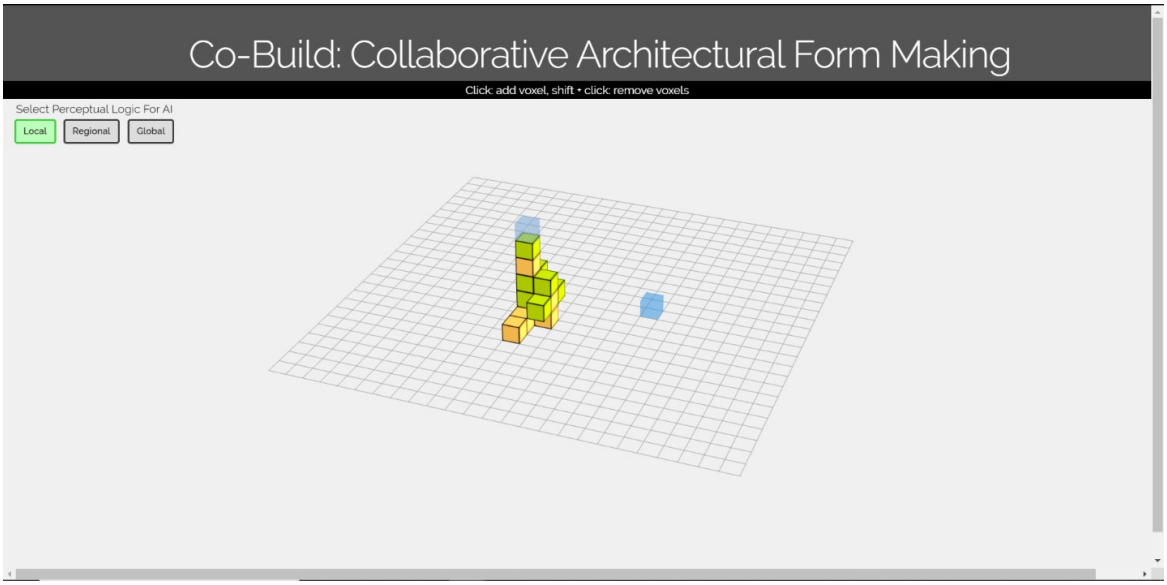

Figure 4.1: Screenshot of Co-Build User Interface

4.1 Web Client

The code for the web client is structured using the MVC (model view control) pattern. All the application logic is built-in on the web client and hence the computation

and interaction happen on the frontend. Since, the code is structured using MVC on the frontend, instead of linking multiple JavaScript files in the HTML, the application uses module bundler - webpack. Basically, webpack processes the application, internally builds a dependency graph which maps every module required by the project and generates one compiled bundled JavaScript file [webpack, 2020].

The code for the frontend is organized as follows- The application has two model classes namely voxel and voxel grid. Voxel class has details relating to a single voxel like its dimensions, color, id, etc. And Voxel grid has information regarding a collection of voxels along with the gird dimensions. The view component is responsible for setting up the Three.js scene, user interface and sending user actions/requests to the controller. The controller is responsible for performing the user's action on the voxels as well as the voxel grid and sending it to the view component. The WebSocket connection is handled by a separate JavaScript file called the Remote Client. This file is responsible for maintaining the WebSocket connection and sending and receiving messages to and from other clients through the web server.

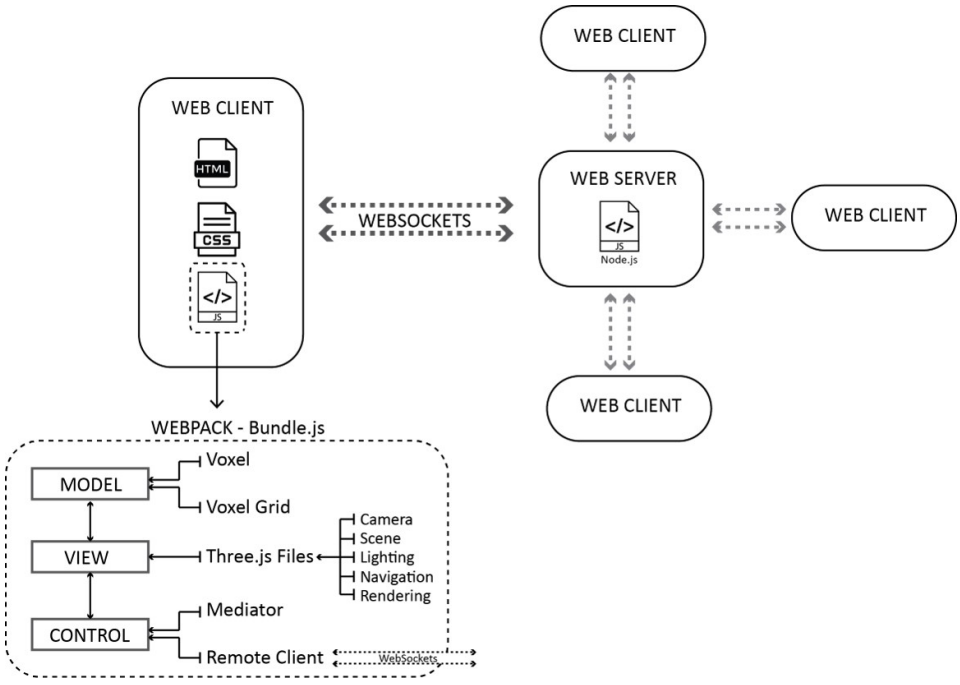

Figure 4.2: Co-Build System Design

4.2 Web Server

The main responsibility of the web server is to receive messages from each web client and broadcast it to other web clients. The server is written in Nodejs and it uses WS library for creating a WebSocket server. When a new client joins, the server will send a list of all the previously executed commands and make sure that the new client is in sync with all the other clients. The entire web application is hosted on Heroku and can be accessed through the following URL - http://co-build.herokuapp.com/

4.3 Basic User Interaction

Since, platform is built as a WebSocket application it can support as many collaborators as needed. But for the purpose of this study the collaboration will always take place between two collaborators. Generally, the application enables any user to add a voxel by clicking on an empty place on the grid or on the face of another voxel they wish to add to. The user can remove a voxel by pressing shift on the keyboard and clicking on the voxel they wish to remove. The user can remove voxels added by them or by another collaborator. Along with this, they can rotate the 3D scene like in any CAD software, by right clicking the mouse and moving in the direction of rotation. The user can also zoom in and out of the scene by using the scroll wheel on the mouse. Along with this the user can select the perceptual logic for intelligent agent- the architecture machine - as described in the following section.For the purpose of this thesis the users will have two kinds of collaboration turn-taking and simultaneous as shown in fig 4.3.

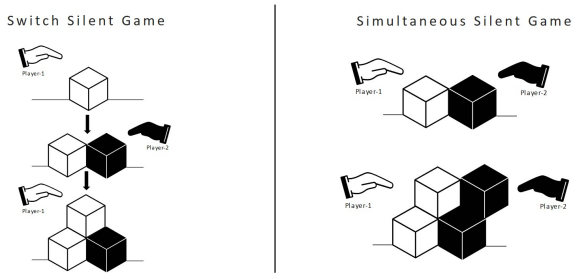

Figure 4.3: Interaction Dynamics Between the Users

4.4 Intelligence for Architecture Machine

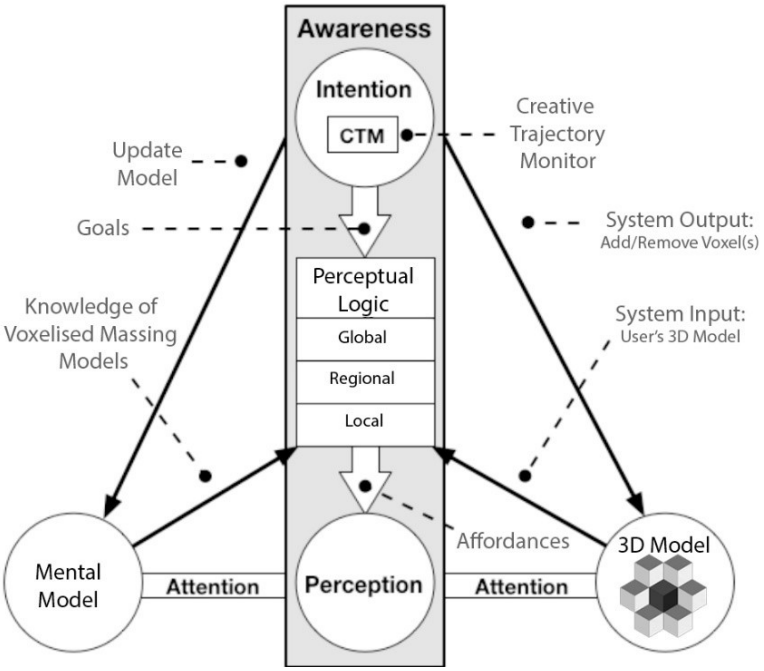

Figure 4.4: Co-Build Cognitive Software Architecture

Even though, the application in its current state has no machine learning or artificial intelligence algorithm implemented. After studying the related co-creative projects, it can be concluded that the Intelligence will be coming from a class of machine learning algorithms called reinforcement learning. Along with this, the algorithm will utilize artificial neural networks like recurrent neural network (RNN), long short-term memory (LSTM), convolutional neural network (CNN) or generative adversarial network (GAN). For this thesis, a wizard of oz study has been conducted in which a human emulates the behavior of an intelligent agent.

The cognitive software architecture for the intelligent agent is based on enactive model of creativity and utilizes the same architecture as utilized in Drawing Apprentice [Davis et al., 2014] as shown in fig 4.4. The primary behavior of the agent is to mimic user's moves. The action sequence for the cognitive model is as follows: as the modelling process begins all the voxels on the voxel-grid are sent to the percep-

tual logic module. The perceptual logic module calls the creative trajectory monitor (CTM) to govern the level of logic, that is - global, regional or local to apply to the current dataset. The CTM has a record of all previous interactions stored in the database forming the mental model of the system. In addition to this knowledge base, the CTM also follows visual design principles like gestalt's eight principles or Christopher Alexander's fifteen principles (fig 4.5) or any other.

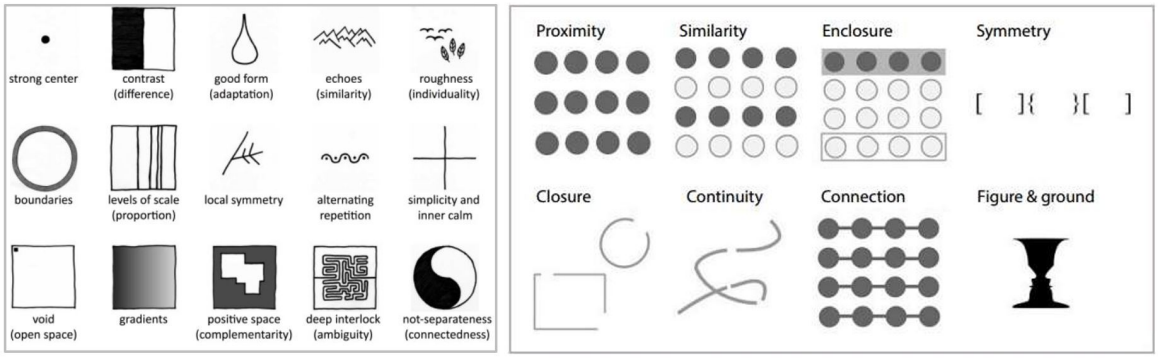

Figure 4.5: (From left to right) Gestalt's visual design principles, Christopher Alexander's fifteen principles of living systems.

With this knowledge base, guiding principles and user's modeling behavior the CTM selects one of the three perceptual logics which determine where the voxels will be added by the system. Local logic takes into consideration user's most recent move and adds/removes voxels around that voxel. Regional logic takes into consideration user's last ten moves and groups the models into region using visual design principles like proximity, similarity, enclosure, etc. and then adds a new voxel region or modifies existing voxel regions. Global logic looks at all the voxels on the screen and again based on visual design principles symmetry, figure ground, and closure, decides where to add/remove the voxels and performs the action. Though the selection of perceptual logic is automatically done by the intelligent agent, users can also choose which perceptual logic the agent should use by selecting the respective button on the user interface.

CHAPTER 5: EVALUATION AND METHODOLOGY

5.1 User Study

Generally, evaluating co-creative systems is still an open research question and there is no standard metric that can be used across specific systems. However, a critical component of co-creative systems is the interaction between machine and human. While there are different frameworks on how to evaluate a co-creative system, I am utilizing the framework described in the paper "Evaluating Creativity in Computational Co-Creative Systems" [Karimi et al., 2018]. The paper provides four questions that can guide the evaluation of the co-creative system namely - who is evaluating the creativity, what is being evaluated, when does evaluation occur and how the evacuation is performed. And summarizes various ways in which existing co-creative systems are evaluated as shown in fig 5.1

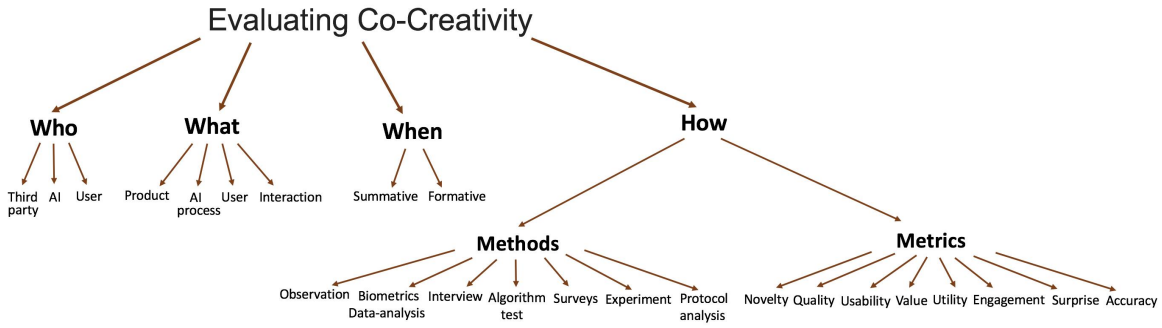

Figure 5.1: A hierarchical tree of evaluating co-creative systems [Karimi et al., 2018]

Even though the enactive co-creative agent based on the creativity trajectory monitor, evaluates the model for deciding its move, the final evaluation is done by the human collaborator. The user can even remove the contribution made by the agent. Evaluation in many co-creative systems is about creativity of the collaborative agent but for this study I am not measuring creativity. So, based on the research goals,

interaction is being evaluated in this project. Specifically, interaction between human - human and human - machine is being evaluated with simultaneous and turn-taking collaboration. The evaluation in both the interactions is summative in nature that the evaluation will be done after the task is complete. Borrowing from the evaluation methods used for the Drawing Apprentice, retrospective semi-structured interview is utilized for evaluating Co-Build. Table 5.1 gives a summary of application of this framework to this study. The user study has been designed to help understand the emergent participatory sense making that would arise out of collaboration between two humans and to test if participatory sense making arises in a human - machine collaboration, where the machine mimics users moves based on the perceptual logic.

Table 5.1: Summary of application of the evaluation framework.

EVALUATION FRAMEWORK		
Who		The User
What		Interaction (Human-Human and Human-Machine)
When		Summative (After the collaboration)
How	Method	Retrospective video walkthrough and Interview
How	Metrics	Collaboration, Engagement, Ownership

5.2 Pilot Study Design

The pilot study consisted of three parts each with a design task followed by a retrospective video walkthrough and interview. In the first task which lasted for 5 mins, the participant was asked to explore the website and make a 3D model by adding and removing voxels on the screen as they see fit. The idea behind this task is to get the participant familiarized with the interface, its controls and navigation.

After the first task the participant was introduced to the rules of the Silent Game

-

- The players are not allowed to talk.
- The participant will be the first player and hence will start the game by laying out a spatial pattern of his/her choice.
- The second player will interpret the pattern and first replicate the pattern as is and then lay out a new spatial pattern either by extending, modifying or adding to the current pattern.
- Then the first player will do the same.
- The game will go on until the facilitator says stop.

After this, participant was introduced to the variations of the silent game namely, the switch and the simultaneous silent game -

- For the switch silent game, turn taking interaction will be applied - Each player after finishing their move will move aside and remain inactive for 2 seconds indicating the other player that it's their turn.
- For the simultaneous silent game both the players will build together. The second player will join after the first player has laid out some pattern, then each player will simultaneously interpret and respond to each other patterns without pausing.

The second task lasted for around 12 mins, where switch silent game and simultaneous silent game accounted for 6 mins each. And the screen was recorded documenting contribution by each player.

After this the participant was informed that the third task will be like the second task but this time they will be collaborating with the machine. Then they were introduced to the perceptual logic settings -

- In local logic, the machine considers the last 2 moves for its output.
- In regional logic, the machine considers the last 10 moves for its output.
- global logic, the machine considers the entire composition for its output.

Again, the third task lasted for around 12 mins, where switch silent game and simultaneous silent game accounted for 6 mins each. The facilitator behaved as the wizard of oz (WoZ) - machine behaving according to the enactive framework. In the local logic mode, the facilitator just copied the latest move done by the participant, in regional mode facilitator copied the user's structure in two directions on the same axis and for global the facilitator mirrored the entire structure. During this task as well, the screen was recorded documenting contribution by the participant and the facilitator (WoZ machine)

Following the tasks, a retrospective interview was conducted. The participant was shown the video of their collaboration and was asked to describe their thought process. Then, a semi structured interview was conducted about various design choices made during each task. After the interview the participant was debriefed and was informed that the third task was a wizard of oz study. This session lasted for approx. 20 mins.

Two pilot studies were conducted, and the following issues were identified:

- Facilitator found the 5 mins long first task of building something to familiarize with the interface unnecessary.
- 5 mins of game play was too monotonous for the participants. By the time WoZ study ended, participants had lost all the interest in the game. Also, during each game the moves were becoming quite repetitive.
- The participants complained about hearing click sound during the WoZ condition which gave it away that they were not collaborating with an agent.

- The idea of understanding and replicating the pattern in the silent game was too complex and the participants and the facilitator found it hard to accomplish.
- The facilitator realized, that in global and regional logic, making mirror image of the entire structure and copying the structure in two direction was a difficult and time-consuming task.
- With the unstructured retrospective interview, it was difficult to meet the research goals and answer the research questions.

To overcome the issues from the pilot study, the study design was modified as described in the section below.

5.3 Study Design

The study was conducted through a video call on google hangout. The study design is summarized in the table below

Table 5.2: Study design.

TASK	DESCRIPTION	DURATION
1	Familiarize the participants with controls and navigation - Participants were asked to pan, zoom, add a voxel on the grid, add a voxel on the face of another voxel, remove a voxel they added and remove a voxel the facilitator added.	2 mins

Continued on next page

Table 5.2 – *Continued from previous page*

TASK	DESCRIPTION	DURATION
	Introduce Silent Game- • The players are not allowed to talk. • The game will start when facilitator says start • The game will end when the facilitator says stop • Participants can make whatever they want to.	2 mins
2A	Switch Silent Game- (turn taking interaction) • Each player after finishing their move will move aside and remain inactive for 2 seconds indicating the other player that it's their turn.	3 mins; screen recorded
	Break	1 min
2B	Simultaneous Silent Game - (simultaneous interaction) • Each player will simultaneously add voxels without pausing.	3 mins; screen recorded
	Break	1 min

Continued on next page

Table 5.2 – *Continued from previous page*

TASK	DESCRIPTION	DURATION
	Introduce Perceptual logic and participant can switch between logics any time • In local logic, the machine considers the last 2 moves. • In regional logic, the machine considers the last 10 moves. • In global logic, the machine considers the entire composition.	2 mins
3A	Switch Silent Game- with machine (WoZ agent)	3 mins; screen recorded
	Break	1 min
3B	Simultaneous Silent Game - with machine (WoZ agent)	3 mins; screen recorded
	Break	1 min
	Retrospective video walkthrough participants were asked to describe their thought process.	5 mins - 6 mins; Transcript noted
	Break	1 min
	Structured Interview	9 mins - 10 mins; Transcript noted

5.4 Post Task Interview Questions

Each participant answered nine questions that were designed in direct relation to the research goals and research questions. Fig 5.2 shows all the interview questions, along with the research goals and research question they relate to. It also shows the relation to the evaluation metrics.

RG - Research Goal; RQ - Research Question

RG & RQ	INTERVIEW QUESTIONS	METRICS
RQ1; RG1; RG3	Did collaboration benefit your design? • Who do you prefer, human or the machine? • Why?	Collaboration
	Were you aiming for a particular design? • Did it change during the collaboration? • (If yes) What and who inspired you with new ideas?	
RQ2; RG1	Was the contribution by the machine making sense? • How did you decide if the contribution of by the machine, made sense? • Did you make use of any visual design principle? • Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?	Engagement
RQ3; RG3	During human – machine collaboration did you feel you had contributed more to the design?	Ownership
	Did you feel that agent was your design partner or a tool? • What features prompted you to think so? • What features from the human – human collaboration should the 'tool' have to make it seem like a partner?	Ownership
RG2; RQ1	Which method (switch or simultaneous) would you prefer to engage with the machine?	Engagement
RG3; RQ1; RQ2	If I hadn't mentioned with whom you were collaborating? Could you still differentiate between machine and human collaborator? • If yes, using what features or metrics?	Collaboration
	What features of human – human collaboration would you like to be incorporated in human -machine collaboration?	Collaboration & Engagement
	How different was human collaboration as compared to the machine collaboration?	Collaboration, Engagement and Ownership

Figure 5.2: Interview Questions

CHAPTER 6: RESULTS

The user study was conducted with 20 participants, 8 females, and 12 males with an average age of 25. Out of 20, 15 participants had a background in architecture and design, and 5 had a non-design background. The participants were recruited through email after they had read and agreed to the consent form (refer appendix A). The data generated from the study include, screen recordings of the design tasks, the transcribed data from the retrospective video walkthrough (refer appendix B) and the transcribed data of post task interview (refer appendix C). Along with this, all the transcribed interview data was simplified and compiled in a table (refer appendix D) to make it easier to analyze and compare the data.

6.1 Overview of Post Task Interview

17 participants reported that collaboration was beneficial for their design process and 3 participants were either not sure or they reported that collaboration had no impact on their design process. With the primary mimicking behavior of the machine (WoZ Human), 17 participants reported that the contribution by the machine, made sense. These 17 participants used pattern mimicking, pattern continuation and creation of similar pattern as the metrics to decide that the contribution was making sense. Also, symmetry, continuity, repetition and proximity were the dominant visual design principles that were employed by the participants to make sense of machine contribution.

With just mimicking, even though majority of participants agreed that machine contribution made sense, all the participants reported that they would like the machine to perform more actions and not just mimic. 13 participants preferred simulta-

neous interaction with the machine as they enjoyed it more or they liked the real-time response from the machine. 4 preferred turn-taking interaction because they had more control over the machine or could monitor and analyze machine's contribution closely.

11 participants reported that they prefer global perceptual logic, 6 of them claimed that they designed by looking at the big picture and machine was doing the same in global setting. Also, 7 of them thought that since machine took into account all the voxels, it had more data to train and learn from. 5 participants preferred regional perceptual logic, because they felt the machine was completing their structure following their design logic. 6 participants preferred local perceptual logic as they claimed that machine was paying close attention to them and was following and mimicking exactly what they were doing. 2 participants reported that local logic can be used to automate monotonous and repetitive tasks.

5 participants reported that the machine was a tool because it was mimicking. 5 participants reported that the machine was more than a tool but less than a partner because the machine followed their design logic and completed their structure. 9 participants reported that it was partner because it either gave them new ideas or they were not able to control the machine fully. One participant thought machine was like an opponent because it was competing with them to place the blocks.

6.2 Human - Human Collaboration

The main aim of studying human - human collaboration is to extract features that can be applied to human - machine collaboration. To do that, analysis has been done on three criteria namely participatory sense making in the collaboration, interaction dynamics and emergent form making.

While 18 participants reported that the collaboration was beneficial, 9 preferred to collaborate with the human. The dominant reason for this was the diverse thinking of human, inventiveness, similar spatial understanding and trust.

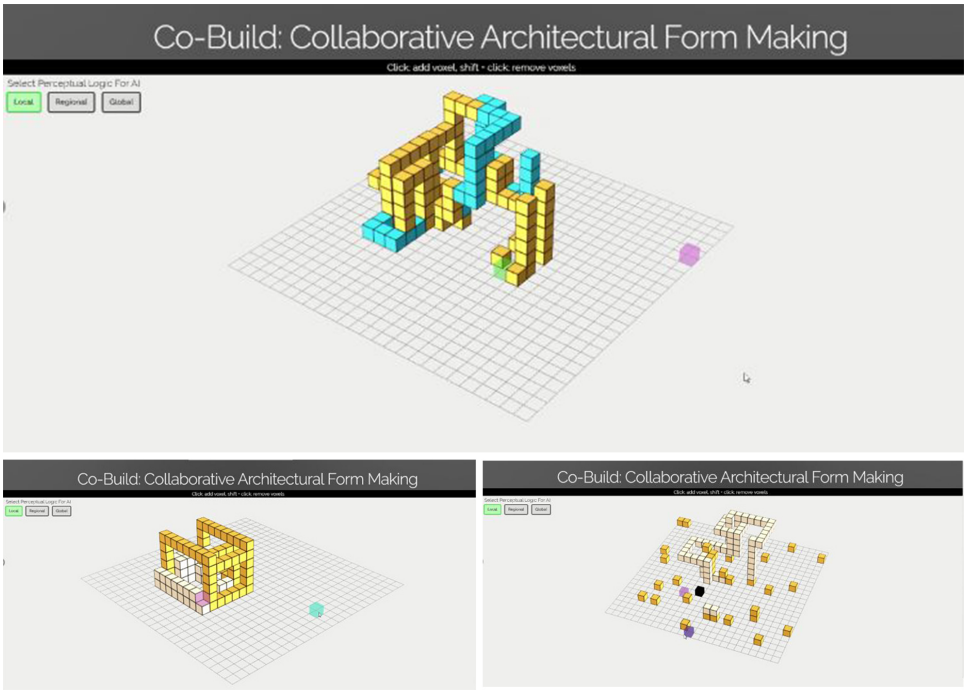

Figure 6.1: Examples of formal outcome in human - human switch collaboration

Figure 6.2: Examples of formal outcome in human - human simultaneous collaboration

6.2.1 Participatory Sense Making in the Collaboration

During the retrospective video walkthrough, 19 participants expressed they got a new idea, for example, P6 expressed this during walkthrough of the simultaneous collaboration -

> "I was thinking at an architectural scale, and I wanted to make big enclosures, but during the collaboration after seeing what the collaborator was doing, I started making modifications to the enclosures and in the end the resulting composition was very interesting."

Another example is from P14 who expressed that the final form was a result of two people working together and they had no prior design that they were trying to achieve. This was during the switch collaboration -

> "Initially I was just exploring the possibilities of the platform, I had no design in mind. But through collaboration I started forming new ideas and adding blocks in places that seemed interesting. I think overall it was good exercise, it was interesting to see how two minds were working with different perspectives to develop a form together."

It is interesting to note that even though P14 agreed that collaboration with human was interesting and got new ideas, P14 preferred to collaborate with the machine. The above cases showcase participatory sense making when they had no design in mind. P3 on the other hand had a design in mind but during the collaboration, the idea changed drastically to something else. P3 expressed this for the switch collaboration-

> "Initially I was trying to make some alphabets, then I changed to make them into a 3D shape. Then based on the collaborators move, I changed my mind, and then I started making two buildings besides each other and connected to each other."

6.2.2 Interaction Dynamics

Usually, the participants during human collaboration either built their design and joined it to the collaborators design or they started making their design in response to the collaborator's design. For example, P11 described the interaction dynamics during the simultaneous interaction as follows-

> "In this case, it was interesting as both me and the collaborator were working together. I started on one side the collaborator started on the other. It was fun and good to see how forms can be made by merging the two."

And at the same time P5 described interaction dynamics during the simultaneous interaction as follows-

> "I was more random in this case, also it was more interesting to me as we could affect each other's decision in real time for example when the collaborator wanted to go straight up, I removed a few blocks and tried to bend it. Then even though I was random I started adding and removing blocks a bit more deliberately, I think this was more exciting."

Participants mostly preferred turn-taking/switch interaction with the human collaborator. P16 sheds light on this as follows-

> "I started with shape without thinking I just put things and the after a couple moves by the collaborator, I started seeing the shape semantically and started to interpret shapes, so from the plan view it looked like a human belly and hence I started adding legs. And then collaborator continued adding blocks to it. It was an interesting process, the switching allowed me to interpret occasionally and change what I want to do based on the actions."

Further P16 described simultaneous interaction as “hectic” and said “had no time and just placed blocks because many things were happening together”

6.2.3 Emergent form making

Emergent form making was a dominant feature in during human collaboration. All participants expressed that the final form was not what they had initially thought of, or they were basing their decision based on the collaborator’s move. For example, P14 expressed the following -

> “So, I again began with no prior thought, but soon based on collaborator’s move I started adding blocks forming a frame and connecting to his structure. Midway I started making contrasting moves, by focusing on making tall, vertical and liner structure. I really like the outcome, the result formation of objects and interlocking of spaces were quite interesting.”

The emergent form making is demonstrated the best in P2’s comments-

> “In this I started off by thinking of building vertical structures; but then I switched to making arches. At the same time my collaborator was adding boxes which looked like supports to the arch so even I added supports based on the collaborators move. later based on all the voxels on the screen I thought it looked like a pyramid and started building a flat pyramid in the vertical plane.”

6.3 Human - Machine Collaboration

The main aim of studying human-machine collaboration is to check, to what degree is participatory sense making present and when does the contribution by the machine make sense. Assuming that the logic of the machine is implemented exactly as described by the enactive framework and the machine just mimics the participant’s response at varying degree depending on the perceptual logic setting set by the participants. To do that, again the analysis has been done on three criteria namely,

participatory sense making in the collaboration, interaction dynamics and emergent form making.

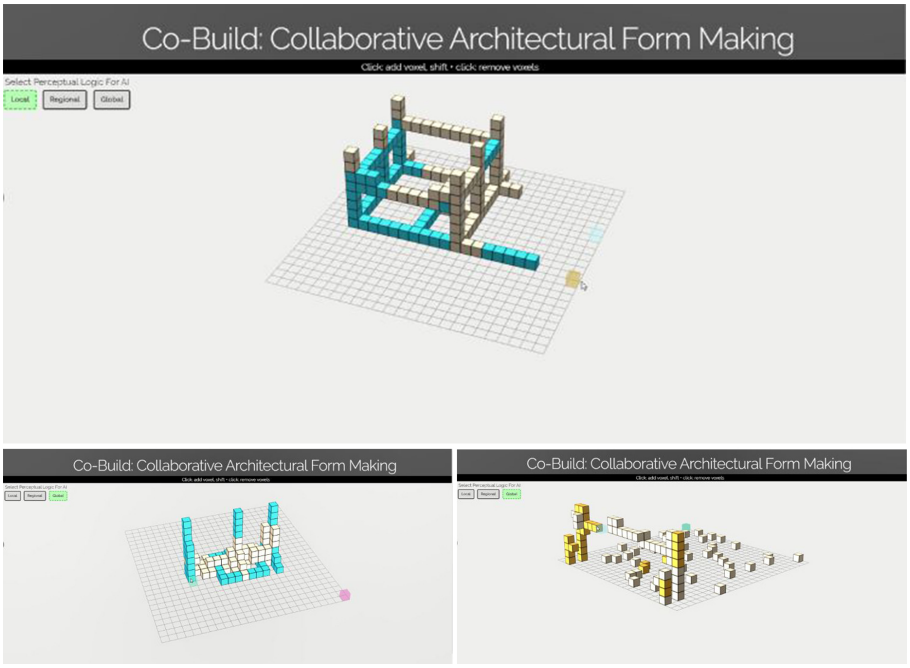

Figure 6.3: Examples of formal outcome in human - machine switch collaboration

Figure 6.4: Examples of formal outcome in human - machine simultaneous collaboration

11 participants preferred to collaborate with the machine. The dominant reason for this was the control on the machine and hence the form, mimicking action of the machine, similar output and design alignment.

6.3.1 Participatory Sense Making in the Collaboration

During the retrospective walkthrough, only 3 participants expressed that they got new idea or new design direction from the collaboration. P2 expressed this during simultaneous interaction-

> "I began with local logic setting, the agent was just extending my moves concurrently; but then I changed the logic to global; then even though it was making symmetric moves it kind of surprised me when it started building something resembling archways or roman aqua ducts. Then I continued with the adding more aqua ducts."

Similarly, P15 expressed the following during the simultaneous interaction-

> "Here also, I wanted to see what the machine was doing, Again I felt that it was replicating my moves. But it did give me a new idea, I was making one line it added another line beside me, so I changed my design to add another line as two lines looked good."

P8 had a similar experience and expressed the following during the simultaneous interaction-

> "Here I knew machine likes to build in linear manner, so I thought of adding heights to staggered form I was thinking. But machine picked up on something that seemed more interesting to me, so I aligned my thought to what machine had produced and started making long linear vertical and horizontal structures."

P8 further adds to that-

> "This was the most interesting of all, because after the initially switch in the logic from local to regional to global, the scheme turned out be quite cohesive."

All the participants were keener on understanding how the machine worked. So, the mindset of the participants changed from collaborating to "let's see how the machine reacts to this move".

6.3.2 Interaction Dynamics

The participants went into testing mode during the collaboration with machine. For P13 deliberately added random blocks and wanting to see if machine detected any pattern that P13 was using subconsciously-

> "So, there is one thought process behind this, that is randomness, I was trying rid myself of using any logic, I wanted to see if machine shows me the logic that I was using when I was thinking that I wasn't using any logic. At the same time, I was switching between different logic modes of the machine. I think it did a good job, it seems like I had some subconscious logic while placing the blocks this was especially evident in global setting when the machine was using the entire grid and kept bringing back my earlier chain of thought."

While P5 expressed frustration and regarded the interaction with the machine as nonsensical in the switch interaction-

> "The machine was basically so dumb, I wanted to see what it can do, so I started off with local and it was just copying me and then I switched to global but it kind of didn't make sense, so I gave up on the machine to do anything and I started focusing on my own thing and towards the end I started adding random blocks."

Another dominant thought was that of the control and authority, as expressed by P12 in simultaneous case-

> "I had figured out how the machine was working, so switched between the logic, like, when I wanted the machine to follow me, I selected local. And when I wanted a global perspective, I selected regional or global. As oppose to other cases in this one tried to focus on one structure instead of spreading it out, the machine behavior was predictable."

2 participants expressed their frustration in the local logic mode as machine was placing blocks before they wanted to place, and 1 participant regarded the machine as a puppy following around in the local setting.

6.3.3 Emergent form making

Even though the machine was just mimicking, the emergent form making was dominant feature during the simultaneous interaction. Even though it was not as surprising as it was in the case of human - human collaboration, the collaboration with the machine produced controlled but diverse emergent and complex forms. This is highlighted in P8's comments regarding the final form in simultaneous interaction-

> "This was the most interesting of all, because after the initially switch in the logic from local to regional to global, the scheme turned out be quite cohesive."

Something similar was expressed by P1 as well-

> "The resulting 3D composition was good, even though it was not as coherent as it was in the case of human collaborator."

6.4 Evaluation Metrics

18 participants reported that the collaboration was beneficial for their design process. While the dynamics of collaboration was different (as explained in the section

above) depending on who the collaborator was. Since the game demanded collaboration, this was an expected outcome.

Engagement can be seen by the fact that 10 participants requested to continue building even after the facilitator said stop. Comparatively, engagement was higher with human collaborator as no participant reported get bored or giving up. Also, even though participants preferred switch interaction with human the engagement was same for both switch and simultaneous case. While in machine collaboration 3 participants explicitly stated that they started adding random blocks, as they gave up on the machine, this happened during the switch interaction. However, all the participants were fully engaged in the simultaneous interaction with the machine.

Ownership varied a lot between human collaboration and machine collaboration. While everyone attributed the outcome for human collaboration as work of two minds. 19 participants claimed sole ownership of the form in the case of machine collaboration. Only 2 participants expressed that in terms of design idea they were the authors but in terms of labor (adding voxels) the machine had contributed equally. It was interesting to also note the degree ownership changed with different perceptual logic settings; in local logic all the participants claimed the entire ownership of the design. The description of ownership for the regional logic changed to- "I started the design the machine extended it/completed it". While for the global logic the description of ownership changed to- "machine contributed to the design by learning and replicating my earlier moves".

CHAPTER 7: CONCLUSION AND FUTURE WORK

In this thesis Negroponte's idea of man-machine symbiosis was investigated. The study was conducted through Co-Build - A real time web based collaborative 3D modelling platform. The aim of the study was to understand the "symbiosis" by-

- extracting different circumstances under which contributions from co-creative agent (machine) appear to make sense.
- extracting different aspect of human - human collaboration that can be applied to human - machine collaboration.

The machine behavior was based on enactive model of co-creativity. For the purpose of the study, machine intelligence was emulated using the wizard of oz technique and the machine action was restricted to mimicking. To simplify the complexity involved in architectural design process, the thesis focused on additive massing models, specifically in the context of concept design game which focused on interaction namely, the silent game. Further two variations of silent game namely, switch silent game and simultaneous silent game were proposed to test two kinds of interactions between the collaborators namely, turn-taking and simultaneous interactions. Further, an online user study with 20 participants was conducted. The user study involved participants playing both the variation of silent games first with a human and then with the wizard of oz machine. Retrospective video walkthrough and post task interview were the methods utilized to collect data for evaluation.

7.1 Conclusions from User Study

Participatory sense making was higher in human-human collaboration as compared to human-machine collaboration. This can be concluded from the fact that the en-

gagement was much more in human-human collaboration. And even though the outcome was not planned and was a result of collaboration, the participants reported less emergent form making experiences with machine collaboration. Participants repeatedly expressed that machine should not just mimic the users; it should also generate new ideas. A variety of methods were proposed by the participants. Few of the prominent ones were randomized voxel placement, mimicking with random mutation, machine initiating the design and setting and working towards a common design goal. It was also revealed that participatory sense making was more in the simultaneous interaction. Within simultaneous interaction, participatory sense making occurred more in regional and global perceptual logic.

Participants used pattern mimicking, pattern continuation and creation of similar pattern as the metrics to decide, if the contribution made sense. Also, symmetry, continuity, repetition and proximity were the dominant visual design principles that were employed by the participants to make sense of machine contribution. Here, it was interesting to note the correlation between ownership and sense making of machine contribution.

Only 5 participants regarded the machine as the tool. While the rest claimed the machine was either more than a tool or they claimed that they saw the machine as a partner. The primary reason for this was that the participants weren't fully able to control the output of the machine. And that the machine was continuing/completing their design.

It was interesting to note the cognitive biases of the participants towards the wizard of oz machine. This was especially evident when participants reported things like time lag, fast response time, accuracy of repetition. Also, it was noticed that all the participants by default, assumed that the machine will be learning from them, even before the collaboration began, while it was not mentioned at all by the facilitator. Another behavior of the participants that highlighted the bias is the quest to test

the limits of the system. Participants conducted mini experiments, especially in the switch interaction and formed an opinion and mental model of the machine.

7.2 Design Recommendations Based on Human Collaboration

The machine can have a "personality"and "design belief system" of its own. Like the case in human-human collaboration, the spatial logic, spatial understanding and the personality of the collaborators played a big part in the collaboration. The machine can be provocative, that is, shouldn't always follow the human, it can make changes to the structures built by the human. The provocativeness of the collaborators was another major contributor to the outcome of human collaboration. It was observed that during human-human collaboration, the removal of voxel was appreciated by both the collaborators. Also, many participants attributed the provocative nature of human as one of the reasons for getting new ideas and hence increased participatory sense making. And lastly, as suggested by all the participant, the machine should not just mimic and should generate and work towards a separate idea.

7.3 Discussion

It was interesting to note that the bar for an entity to be considered as a design partner is very low. As previously stated, majority of the participants considered Co-Build in its current state as a partner. The difference currently between Co-Build and any CAD software is that, in CAD software the user must explicitly give specific commands to the machine like extrude top surface of the box by a unit length, etc. Whereas in Co-Build the machine detects the user's moves and performs it. This subtle change seems to be the main reason as to why the participants considered Co-Build as a partner.

The participatory sense making from the point of view of the machine was restricted to be purely geometric in nature. For example, during the WoZ Human - Machine collaboration, in local logic, the machine would replicate user's moves that is, voxels

were added in the direction and location where the participant last added a voxel. There was no syntactic or semantic analysis that was carried out. While it would have been easy to simulate that machine understood the semantic meaning, as it was a wizard of oz study, it was deliberately kept simple to keep it attainable. The existing machine learning algorithms and data are not enough, it was discovered during this study, that there is no data bank which can be used to train machine on building 3D objects collaboratively.

Using the enactive model of creativity facilitates, not only emulating a designer's way of thinking, it also facilitates a method for data labelling which can be used for machine learning. When the participant changes the perceptual logic settings between local, regional and global, participant is also informing or labelling his/her own moves. When sufficient data is available this can be utilized by the machine to automatically switch between logics.

7.4 Future Work

The current system just allows interaction through website. One possible direction of work would be to explore the same system with integration of interactive and physical computing. This would facilitate other modes of interaction with the system. This should significantly change the user interaction with the system. And just mimicking action by the machine would also seem very intelligent.

The second direction is investigating human - human - machine interaction. That is two humans collaborating with a mimicking machine. This should also drastically increase participatory sense making, and this would provide the opportunity of implementing different mechanisms for the machine to choose between which human to mimic.

The third direction is building the A.I. system with all the design recommendations mentioned in the above section and to test the system again. Here it would be interesting to see if participants are able to identify when they are collaborating with

the human and when they think they are collaborating with the machine.

The fourth direction would be to explore and study other co-creativity metrics like novelty, creativity, surprise, etc. First on the same system and then on the revised system which incorporates the design recommendations.

When participants were asked if contribution by machine "made-sense" - it was interesting to note that it is not clear if the participants were evaluating the emergent 3D massing or they were evaluating the machine logic and the way the machine behaved. On analyzing the transcripts, it can't be said for sure what the participants were evaluating. And this an interesting avenue for further exploration. Further it will also be interesting to explore when the machine contributions stop making sense in the same given setup.

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APPENDIX A: CONSENT FORM

Department of Architecture
9201 University City Boulevard, Charlotte, NC 28223-0001

Consent to Participate in a Research Study

Title of the Project: Co-Build: Co-Creative Architecture Machine for Form Making Principal Investigator: Manoj Deshpande, School of Architecture and Software And Information Systems Faculty Advisor: Eric Sauda, School of Architecture

You are invited to participate in a research study. Participation in this research study is voluntary. The information provided is to help you decide whether or not to participate. If you have any questions, please ask.

A.1 Important Information You Need to Know

- The aim of this research is to study and gather requirements for building a co-creative system comprising of human and an intelligent fabrication machine. The designer will play a concept design game in collaboration with another designer or intelligent agent on web application, the outcome of this co-creative collaboration is expected be an architectural massing model.

- We are asking the participants to play different scenarios in a concept design game with the intelligent virtual agent on a website. This study will include three (3) tasks and a post-task interview. We'll ask you to come to our research lab and complete the design tasks and the interview in the lab that will take about 45 minutes. During each design task screen will be recorded for the retrospective interview. The screen recordings will be stored in google drive on

a private folder will be destroyed in 2-3 months after the study ends

- Please read this form and ask any questions you may have before you decide whether to participate in this research study.

A.2 Why are we doing this study?

The purpose of this study is to study and gather requirements to build a co-creative system comprising of human and an intelligent machine. It is to better understand if such collaboration will facilitate conceptual design explorations through iterative prototyping.

A.3 Why are you being asked to be in this research study?

You are being asked to be in this study because you have a design background, age 20 and older, or you are a student/faculty at UNC Charlotte.

A.4 What will happen if I take part in this study?

If you choose to participate you will complete 3 design tasks and an individual interview. In the first task you will be asked to move manually to assemble a massing composition from the 3D voxels as you see fit on the web interface. In the second task the user will be made to play switch and simultaneous silent game first with a human collaborator on the web interface. In the third task user will play switch and simultaneous silent game with the intelligent agent on the web interface. We will give a brief description and demonstration before each task. Following this in the interview we will ask a series of questions about various design choices made during each task. Your total time commitment if you participate in this study will be one 45 minutes. 10 minutes per task.

A.5 What benefits might I experience?

You might get a new inspiration for design or process of design as a result of participating in this study. Apart from this you will not benefit directly from being

in this study.

A.6 What risks might I experience?

We do not expect any risk in this study.

A.7 How will my information be protected?

You are asked to provide your name and email address as part of this study. Data will be stored on a password-protected computer in a locked office. Identifying information will not be stored with the data. Physical artifacts from the study (massing models/ configurations) will be photographed and then destroyed. The photographs will be stored on a password-protected computer in a locked office. Only the research team will have routine access to the study data.

A.8 How will my information be used after the study is over?

After this study is complete, study data may be shared with other researchers for use in other studies without asking for your consent again or as may be needed as part of publishing our results. The data we share will NOT include information that could identify you.

A.9 Will I receive an incentive for taking part in this study?

There is no incentive for taking part in the study.

A.10 What other choices do I have if I don't take part in this study?

It is an optional study. Participating in this study is voluntary.

A.11 What are my rights if I take part in this study?

It is up to you to decide to be in this research study. Participating in this study is voluntary. Even if you decide to be part of the study now, you may change your mind and stop at any time. You do not have to answer any questions you do not want to answer.

A.12 Who can answer my questions about this study and my rights as a participant?

For questions about this research, you may contact Manoj Deshpande, mdeshpa4@uncc.edu or Prof. Eric Sauda, ericsauda@uncc.edu.

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Office of Research Compliance at 704-687-1871 or uncc-irb@uncc.edu.

A.13 Consent to Participate

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. You will receive a copy of this document for your records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I understand what the study is about and my questions so far have been answered.

I agree to take part in this study.

Name (PRINT)

Signature and Date

Name, Signature of person obtaining consent and Date

APPENDIX B: POST TASK RETROSPECTIVE VIDEO WALKTHROUGH-TRANSCRIPTS

B.1 Participant-1

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  Initially I was just trying to see what all I can do with the platform. Later, I started noticing and following what the human collaborator was doing, from here I got the idea of frames from during the collaborator's move and then I continued adding frames in subsequent turns in different 3D planes.

- human - human collaboration (simultaneous):

  In this, since I knew what the platform can do, I started building vertically up, initially I was focusing just on making my structures, later I started making connections between my structure and the structure being made by the collaborator. This whole idea "joining structure" gave rise to an interesting spaces and complex and layered 3D form.

- human - machine collaboration (turn-taking):

  Here I wanted to see how the machine works, so majority of time I was trying to make sense of the machine was doing by changing logic or making patterns, I realized that machine was replicating my moves, especially in local logic. In global however it seemed like machine was able to understand my intention better and it started taking cues from my previous moves and it added blocks. Since, I focused on machine, I didn't pay much attention what the overall composition looked like.

- human - machine collaboration (simultaneous):

  This was chaotic but was fun, here again I was playing with various logic, in

local the machine just replicated exactly, I global I felt it was mirroring my moves in 3D. However, global was the most fun, like generally also we look at big picture while designing. In regional I couldn't understand what it was trying to do. The resulting 3D composition was good, even though it was not as coherent as it was in the case of human collaborator.

B.2 Participant-2

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I started by making l-shape, laid out voxels flat all on one level and then based on the vertical moves done by the collaborator, I started building vertically as well. Then I guess we both were working on making enclosures of various scales.

- human - human collaboration (simultaneous):

  In this I started off by thinking of building vertical structures; but then I switched to making arches. At the same time my collaborator was adding boxes which looked like supports to the arch so even I added supports based on the collaborators move. later based on all the voxels on the screen I thought it looked like a pyramid and started building a flat pyramid in the vertical plane.

- human - machine collaboration (turn-taking):

  I started off with just playing around with the settings of the logic control to see what the machine comes up with. I began with setting the logic to regional; I realized the machine was finishing my structure. Then I set it to global and I realized the agent was creating a reflection of my structure. And finally, in local I guess it was just copying me.

- human - machine collaboration (simultaneous):

  I began with local logic setting, the agent was just extending my moves concurrently; but then I changed the logic to global; then even though it was making

symmetric moves it kind of surprised me when it started building something resembling archways or roman aqua ducts. Then I continued with the adding more aqua ducts.

B.3 Participant-3

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  Initially I was trying to make some alphabets, then I changed to make them into a 3D shape. Then based on the collaborators move, I changed my mind, and then I started making two buildings besides each other and connected to each other.

- human - human collaboration (simultaneous):

  I started off by trying to make a vertical structure, then based on collaborators move, I transitioned to make a horizontal slab, like a hollow cuboid or a balcony. Then the collaborator started to adding supports to slab from ground. And I continued connecting the structure at the top but then I ran out of time.

- human - machine collaboration (turn-taking):

  First, I started by thinking that I want to do something in 3D that is common. But then after the first move by the machine, I changed my mind and started making a very big cuboid. I saw that machine was also doing the same and copying my moves on the other side.

- human - machine collaboration (simultaneous):

  Here, I started off with the agenda of filling up the entire canvas with vertical and horizontal 3D lines. I was at the same time interested in see if the machine can understand my thoughts and I constantly changed between local, regional and global. In the starting machine when the logic was set to global, the machine

completed the same steps as mine from the other side. But when I switched to regional, it started completing my steps which was amazing. I felt like it started doing something that looked like tiling at a lower level that I wasn't intending to do.

B.4 Participant-4

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  First, I began by just laying out a few voxels in a straight line on the grid, here I had no design in mind. But when I saw the human collaborator going vertically up, I quickly did the same. Then I had the I idea of making architectural framework, so I started adding frames in different direction corresponding to the collaborator's move.

- human - human collaboration (simultaneous):

  I began with the same Idea of architectural framework, but this time I wanted the frames to cover the entire grid, so started making big frames. I midway I realized it was taking to much time. So, I left my framework and started adding supports to small frames my collaborator had added.

- human - machine collaboration (turn-taking):

  Here, I wanted to see what the machine comes up with if I gave it a tower like structure, I realized it just extended my structure. Then I added a few random blocks at the base and switched the logic to global, I some how felt like it was learning from my moves, I like the output in this mode. I completed the structure by making it into a frame and then made switched to regional. Machine again learning from me completed a smaller frame.

- human - machine collaboration (simultaneous):

  From previous game, I liked the global and regional mode, so for this I switched

to regional right from the beginning. The machine as expected understood my design thoughts and started replicating it. Then just to have fun I changed the logic to global, and machine started building and replicating what I had done on the other side. In the end 3D composition looked very balanced and symmetric.

B.5 Participant-5

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was mostly random. But initially I was getting hints from the human collaborator on when to go horizontal and when to go vertical. The form got intrigued from there and the I wanted to see what I can do with this platform as I haven't used it before. I would say over all it was interesting.

- human - human collaboration (simultaneous):

  I was more random in this case, also it was more interesting to me as we could affect each other's decision in real time for example when the collaborator wanted to go straight up, I removed a few blocks and tried to bend it. Then even tough I was random I started adding and removing blocks a bit more deliberately, I think this was more exciting.

- human - machine collaboration (turn-taking):

  The machine was basically so dumb, I wanted to see what it can do, so I started off with local and it was just copying me and then I switched to global but it kind of didn't make sense, so I gave up on the machine to do anything and I started focusing on my own thing and towards the end I started adding random blocks.

- human - machine collaboration (simultaneous):

I felt it was a better experience than the switch case, but the machine contribution still didn't make sense to me. I think it wasn't creating enough and wasn't learning from me. And In this I tried all the settings local, regional and global to make sense of what the machine was up to. But, for me the local was more interesting as at least the machine following me around and kind of playing with me. But otherwise it was not good.

B.6 Participant-6

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  Initially I hadn't thought of any design, I was just exploring the platform. But when the collaborator added vertical blocks, I sort of had an idea regarding how that can be converted into a space at architectural scale. So, I started forming enclosures and sort of gateways in collaboration with the human.

- human - human collaboration (simultaneous):

  In this, from the beginning, I was thinking at an architectural scale, and I wanted to make big enclosures, but during the collaboration after seeing what the collaborator was doing, I started making modifications to the enclosures and in the end the resulting composition was very interesting.

- human - machine collaboration (turn-taking):

  Here, first I wanted to explore what the A.I. is capable of, so I tried to reduce the scale and make smaller things. I initially started of with local logic, the A.I. was just extending my structures, then I switched to global logic, here I felt like the A.I. agent was mirroring my actions. Then I switched to regional, but I couldn't understand what logic the machine was using, I could see that it was following my design direction.

- human - machine collaboration (simultaneous):

  This was the most fun, I wanted to test the A.I more so even though It was simultaneous, I added pairs of blocks in a line, set the logic mode to local and waited for a while, the A.I. just repeated the same steps over and over again. Then based on that I started adding more structure and the agent was following me around then I switched to global logic and the agent mirrored my actions on the opposite side of the grid.

B.7 Participant-7

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I started with added blocks making rectangular blocks of different depth and heights. Later seeing the collaborators move, I changed to making rectangular frames. Majorly during this game, I was trying to see what kind moves can be made on this platform.

- human - human collaboration (simultaneous):

  In this basically, I again started making rectangular blocks and frame but responding to what the collaborator was doing, like making shapes, volumes and spaces that complement collaborator's structure. Later I started looking at joining the two structures in different ways that form interesting shapes and structure. At the end the 3D composition was abstract with varied spatial characters.

- human - machine collaboration (turn-taking):

  I was trying to sense how the machine will react to a bunch of blocks I had placed in terms of spacing, volume, no. of blocks, etc. I didn't bother changing the logic settings and let the machine be in local logic mode. I sensed that it was basically continuing the recent blocks that I had placed.

- human - machine collaboration (simultaneous):

  In this my main aim was to play around with the logic settings and see how machine responds to my structure. I noticed that irrespective of what logic I choose the machine was basing its moves on what I had done, it was copying it but in different ways. I could understand that in regional mode it continued and completed my design. In local it was just copying my move and in global it was making moves similar to my previous moves.

B.8 Participant-8

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was looking at building stepped cubic structures. But then I started responding to the blocks and moves that the collaborator made, like I started building vertically up when I saw the collaborator doing it. Later I filled up the rectangular frame the collaborator had made by adding blocks at the center.

- human - human collaboration (simultaneous):

  In this I was focused on the what I wanted to make so initially I built independently of the collaborator. But after a few blocks, I started connecting structures made by both of us by adding linkages. Later I switched back to my stepped cubic idea and started building that while the collaborator focused on what he was building. Overall, the composition was looking quite complex.

- human - machine collaboration (turn-taking):

  In this I was switching through various logic to see how machine was reacting , even though I wanted to build staggered form, the machine was building very linearly, but through various logics the machine I guess looked at different things and hence the contribution by the machine was different in different logic. And

structure turned out to be completely different from what I had initially thought off.

- human - machine collaboration (simultaneous):

  Here I knew machine likes to build in linear manner, so I thought of adding heights to staggered form I was thinking. But machine picked up on something that seemed more interesting to me, so I aligned my thought to what machine had produced and started making long linear vertical and horizontal structures. This was the most interesting of all, because after the initially switch in the logic from local to regional to global, the scheme turned out be quite cohesive.

B.9 Participant-9

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was trying to put the blocks in a way that it creates something meaningful like making a pattern. I was first laying out blocks on the grid with equal spacing, but after I saw the collaborator going vertical up and making frames, I started doing the same for the blocks I had laid out.

- human - human collaboration (simultaneous):

  From the beginning my intention was to complete the structure in a meaningful way, by forming complex 3D frames. But midway, I decided to add support structure for the collaborator's frames.

- human - machine collaboration (turn-taking):

  I think it was same as with the human so was trying to make patterns and see how machine understands and learns from them. I set the logic to regional as it takes more data for training. Also, to give more data points to machine I almost made the entire frame. Machine followed my logic and completed the

frame. Later I switched to global mode since we had enough data, I felt in this mode machine aligned with my thoughts more.

- human - machine collaboration (simultaneous):

  I had the same idea of frames going into this as well. Here I wanted to test the local mode, it felt like machine was just adding block beside mine. After adding a fair amount of blocks I switched to global mode and was seen before since machine had more data to train on, it aligned to my thought process better.

B.10 Participant-10

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I didn't have a design In mind, I just wanted to see where the collaboration leads to, so I randomly added blocks in a corner, but after the collaborator made an L-shape structure, I got new ideas and continued working the L-shape on a different level. I feel in this we complemented each other's mover very well and the final form shows it.

- human - human collaboration (simultaneous):

  Here, again I didn't have any design logic from get go. But I laid a L-shape flat on the grid following the same logic from the previous collaboration, the human collaborator started adding similar L-shape, but this time It felt like skeleton of a space, so I continued treating it as enclosures and added more structures that correspond well with what the collaborator was building.

- human - machine collaboration (turn-taking):

  In this I thought machine would switch logic on its on and had kept local logic all the time. Again, I had no design that I was aiming for but, I wanted to see what the machine would do, so made some intertwined structures, but it seemed like

machine was just extending my structure. It wasn't making anything random. But it was doing its own thing and didn't feel like it was complementing my moves.

- human - machine collaboration (simultaneous):

  In this I wanted to play around with different logic settings so changed the logic mode very frequently. This was much more fun and engaging. I wanted to see if machine can replicate my staircase in local mode it did as it was following me around. Then I switched to regional mode, I felt machine was completing my incomplete designs. I enjoyed this mode the most. Then I tried global, but it wasn't following my moves that closely, so I switched back to regional. The composition overall was very complex. And in this machine was complementing my moves better.

B.11 Participant-11

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  It was more of learning process, for example I was just looking at x-y plane initially and then switched to z-axis also.

- human - human collaboration (simultaneous):

  In this case, it was interesting as both me and the collaborator were working together. I started on one side the collaborator started on the other. It was fun and good to see how forms can be made by merging the two.

- human - machine collaboration (turn-taking):

  It was good, I started with the local logic, I saw that machine was kind of copying my moves. Then I switched to regional and then global, I saw that machine was replicating my moves and maintaining symmetry.

- human - machine collaboration (simultaneous):

  I again started with the local logic; the machine was placing the block right beside mine. I did not like this and then switched to global as the machine would consider the entire composition. And as expected, machine started replicating my moves while maintaining symmetry. This was fun.

B.12 Participant-12

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  In this I just wanted to fill the entire grid first, and then build over it. At the same time the collaborator was focusing on one structure and was adding blocks at different level, so even I started building vertical structures.

- human - human collaboration (simultaneous):

  In this one, the collaborator worked on one side while worked on the other. And later we started connecting and building around each other's structure. The outcome was unexpected and complex looking.

- human - machine collaboration (turn-taking):

  Here, I was first figuring out what the machine was doing, and like human collaboration I tried to fill the entire area first and then build on top of it. I felt in regional and global machine was trying to complete my structure based on my previous moves, and in local it was replicating my moves. The outcome in this case was very abstract.

- human - machine collaboration (simultaneous):

  Here, I had figured out how the machine was working, so switched between the logic like when I wanted the machine to follow me, I selected local and when I wanted a global perspective, I selected regional or global. As oppose to

other cases in this one tried to focus on one structure instead of spreading it out, the machine behavior was predictable, but the overall outcome was quite interesting.

B.13 Participant-13

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was trying to create some frames in both verticals and horizontal axis. During the entire collaboration I was trying to create some sort of spaces between the blocks. The overall massing does show this synergy between two people.

- human - human collaboration (simultaneous):

  In this one, I started with placing a lot of blocks in different areas and then trying to combine all of them. And at all time I saw what the collaborator created and was trying to create contrast between the kind spaces that were being created and at the same time in the kind of massing that was happening. The over form reflects that, the green blocks form tall spaces while the blue ones form small spaces and are intertwined in parts.

- human - machine collaboration (turn-taking):

  So, I started with the idea of reverse pyramid, I wanted to put one face, and wanted to see how machine responds, I was expecting the machine to do the same in another plane. But It did not, but when I started adding blocks in another plane and switched the logic to regional the machine caught up and added the perpendicular lines forming an enclosure.

- human - machine collaboration (simultaneous):

  So, there is one thought process behind this, that is randomness, I was trying rid myself of using any logic, I wanted to see if machine shows me the logic that

I was using when I was thinking that I wasn't using any logic. At the same time, I was switching between different logic modes of the machine. I think it a good job, it seems like I had some subconscious logic while placing the blocks this was especially evident in global setting when the machine was using the entire grid and kept bringing back my earlier chain of thought. Overall, the composition and spaces that were created as a result are abstract.

B.14 Participant-14

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  Initially I was just exploring the possibilities of the platform, I had no design in mind. But through collaboration I started forming new ideas and adding blocks in places that seemed interesting. I think overall it was good exercise, it was interesting to see how two minds were working with different perspectives to develop a form together.

- human - human collaboration (simultaneous):

  So, I again began with no prior thought, but soon based on collaborator's move I started adding blocks forming a frame and connecting to his structure. Midway I started making contrasting moves, by focusing on making tall, vertical and liner structure. I really like the outcome, the result formation of objects and interlocking of spaces were quite interesting.

- human - machine collaboration (turn-taking):

  I was keener to understand how the algorithm was functioning and I was at the same time reflecting on my thought process in the formation of the shape. I was only able to check the regional and local logic; I felt the machine was performing better in global logic completing and adding to my design cohesively.

- human - machine collaboration (simultaneous):

  I think in this scenario, I really got busy with developing an interesting form, but halfway through I realized that the algorithm was mimicking my thought process behind this. The final outcome is very evident of that, I had set the logic global and the structure looks symmetric and complements the design perfectly.

B.15 Participant-15

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  So, I didn't have any specific thought process, but what I tried do was to give the structure a little bit support, I was also thinking what the collaborator was making and added support to that structure as well. Majorly I placed the cubes randomly, but not too random, I was placing them in a manner that it can be built in real world.

- human - human collaboration (simultaneous):

  In this case, I was looking at it in a plan view and was adding blocks randomly the I switched to the 3D view to see what form the cubes were making and then I was just trying to give support to my cube placement and as well as the collaborators cube placement.

- human - machine collaboration (turn-taking):

  In this case, I was trying to think how the machine was building, what I felt was it was somehow replicating my steps and following my steps, so what I tried to do is to see how to machine reacts to different cube placements. I guess my thought process changed from providing support to figuring out the machine.

- human - machine collaboration (simultaneous):

  Here also, I wanted to see what the machine was doing, Again I felt that it was

replicating my moves. But it did give me a new idea I was making one line it added another line beside me, so I changed my design to add another line as two lines looked good. In the first two minutes, I was populating cubes and then later I randomly started reducing or removing the cubes and I wanted to see how the machine responds to that.

B.16 Participant-16

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I started with shape without thinking I just put things and the after a couple moves by the collaborator, I started seeing the shape semantically and started to interpret shapes, so from the plan view it looked like a human belly and hence I started adding legs. And then collaborator continued adding blocks to it. It was an interesting process, the switching allowed me to interpret occasionally and change what I want to do based on the actions.

- human - human collaboration (simultaneous):

  This was more hectic, I started placing blocks, but since there was extra stuff happening, I had less time to do an aesthetic or semantic evaluation of what I was building. So, my actions were local, so I stared to create curvy objects and I started to connect objects. This kind of move me to be action oriented rather than what I want to build, I just added blocks that were connected.

- human - machine collaboration (turn-taking):

  What I did was see what each of the logic meant in terms of results, so tested the logic first. Local I realized It doesn't mean anything to me, I moved to regional and it was interesting. I switched to global first, which looked it allows me more space. So, since it's the switch case, I had the ability to process the information and observe what the collaboration is doing.

- human - machine collaboration (simultaneous):

  It was like the other one, I changed the logic mode for A.I. randomly. I wanted to interpret what was happening, but I couldn't. It became like game of seeing what the A.I. was doing and connecting things together, it was fun exercise of"hey where is that at". The local mode in this was a bit annoying the A.I. blocks and stops you from doing what you want by placing the blocks before you do, there is less chance of that happening in global.

B.17 Participant-17

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  Basically, since I had never used the platform, Initially I had to get a hang of the platform. It was interesting to see that the we were doing completely different things, Also I was restricting myself only in the horizontal plane, but after collaborator made things in the z-axis, I also started adding blocks vertically. The product showed how collaboration with different thinking can lead to something good.

- human - human collaboration (simultaneous):

  This was a bit chaotic, there were so many things that was happening at once it was difficult to follow one pattern, I got distracted midway to see what the collaborator was doing. But then I got back what I was doing. It started out chaotic but is somehow organized itself well in the end. And I actually like the outcome.

- human - machine collaboration (turn-taking):

  So, it was interesting to see how machine was trying to learn from what you were doing. Especially, after switching different logic, you can see how machine

is learning from the pattern and trying to make something similar out that pattern. I felt like machine was trying to closely follow my moves.

- human - machine collaboration (simultaneous):

  This was the most fun, the machine was following me everywhere, in local logic it completely imitated what I was doing, it usually put block beside mine or over mine. In regional logic, I felt like if put one block, the machine would put ten blocks following the same logic. I didn't global logic completely, but it somehow was placing the blocks following my logic. So, midway I was trying to distract the machine also, so I would randomly placed blocks to see the machine follow me around like a little puppy.

B.18 Participant-18

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was trying to design my own layout at first. But based the collaborator moves I was able to see new possibilities that were more interesting, for example - going up in the vertical direction or connecting in air and building downwards. So, I started taking cues and building around collaborator's design.

- human - human collaboration (simultaneous):

  In this one, I was trying to focus on my own design and then tried to see how that interwove with the collaborator's design. I guess we both had different ideas to begin with so at the end the structure shows blend of two designs.

- human - machine collaboration (turn-taking):

  In this one, I was trying to create a structure similar to the one I had in the switch game with human. I built a connected structure and had set the logic to regional so that computer has more data to work with. Computer made its

move like joining structure. I then based off computer's move, was trying to create and maintain the same topology.

- human - machine collaboration (simultaneous):

  For this, I went in with no prior design idea and I was interested in experimenting with all the different logic possibilities. I saw local logic was directly influenced by my design and was following me very closely. While in global, it was somehow indirectly influenced and wasn't building as close to me as earlier. Regional logic was somewhat in the middle, because it wasn't too close but not too different from my moves, it was roughly close to my design. This was fun and the outcome was quite good.

B.19 Participant-19

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I just wanted to spread the blocks around the grid and didn't want to build upon one thing. Also, there was no logic that I was following when I was spreading the blocks around.

- human - human collaboration (simultaneous):

  In this I was trying to make a cat face made of pixels, when the collaborator was trying to build upon one thing. I was busy making, eyes, ears etc. Then I saw that there is not much real estate on the grid so now I wanted to just go vertically up in one line, so I started building that.

- human - machine collaboration (turn-taking):

  First thing I quickly realized that in local it started to build on top of what I had built in the last move. So, I switched to global to see what the machine would do, but I didn't understand what it was doing, it didn't make sense to

me when I scattered the blocks around, I guess even the machine was scattering it.

- human - machine collaboration (simultaneous):

  Again, first few bits when the logic was set to local, the machine was trying to add another cube right by my cube. So, I switched the logic to global and regional a couple of times to throw the machine off my trail. And I was just adding a cubes where there were voids, the machine did completely different.

B.20 Participant-20

Describe your thought process during thought process during:

- human - human collaboration (turn-taking):

  I was first exploring the platform as to what it can do. I just randomly added blocks of different height, but after I the collaborator's move, I started connecting the structures. And started playing around with different block placements.

- human - human collaboration (simultaneous):

  I was just creating a set of blocks of different heights and played around with the concept of linking the structures. I was majorly focusing on my structure, but occasionally saw what the collaborator was doing and added some more linkages between mine and the other structure.

- human - machine collaboration (turn-taking):

  I was trying to explore how the machine responded in different logic settings. To begin with I just made an L-shape and the machine added blocks on top my L-structure, so I continued building on top of it, in regional it started linking different parts with a straight line and in global as took into consideration all the blocks, it made moves following mine on the other side of the structure. I think the structure looked somewhat symmetric.

- human - machine collaboration (simultaneous):

  I enjoyed this the most, I wanted to make symmetric structure. So, until I had enough blocks on the grid, I had kept the logic to local, I saw machine was accompanying my blocks, later I switched to regional when again machine was linking structures and then global. I think the machine in global mode made partly symmetric moves based on my design.

APPENDIX C: POST TASK INTERVIEW - TRANSCRIPTS

C.1 Participant-1

- Did collaboration benefit your design?

  Yes, definitely.

  - Who do you prefer human or the machine?

    The Human, for sure.

  - Why?

    With human my mind is at peace, I have a "design trust", since the collaborator also has a background in architecture it felt like we had the similar design thoughts. I had an approach and I had mine and during simultaneous game, we literally merged our design thoughts, I guess the 3D form at the end is very evident of that.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No, I am not sure. Maybe I would have in local logic.

  - If yes, using what features or metrics?

    Because the machine was just copying me, for a human it would have been difficult. Also, there was some lag in response of the machine.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  I guess like with human case the machine should take cue from designer and not just copy. The machine should give new ideas, like may be make random moves by adding blocks or make suggestions based on designer's idea.

- How different was human collaboration as compared to the machine collaboration?

I felt no difference with was happening with the 3D model. The collaboration was also very similar, its just that machine didn't produce anything new.

- Were you aiming for a particular design?

  No, but I got various ideas on what can be done.

  - What and who inspired you with new ideas?

    Human, during both the games as I said I got the idea of frames form what the human had made in the switch game.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  I prefer the switch case as it was easier to respond. And I feel it might go out control otherwise.

- Was the contribution by the machine making sense?

  Yes, it was.

  - How did you decide if the contribution of by the machine, made sense?

    It made pattern out the pattern already there, nothing totally random so it made sense.

  - Did you make use of any visual design principle?

    Yes, probably Continuity, Symmetry, Repetition.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes, I did, Global made a lot of sense, when I had significantly added blocks; local made sense when I wanted the machine to replicate what I had done.

- During human - machine collaboration did you feel you had contributed more to the design?

  Not sure, but design conception wise yes.

- Did you feel that agent was your design partner or a tool?

  It was more than tool less than partner.

  - What features prompted you to think so?

    I think the time lag, the whole idea of changing different logic, also regional logic was not clear.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Giving space to the designer response and not responding at crucial times in design; so that it doesn't create confusions.

C.2 Participant-2

- Did collaboration benefit your design?

  Yes, it resulted in some unexpected outcomes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    Human was unpredictable while machine was using the same logic, so it was easier to work with.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes, I would have.

  - If yes, using what features or metrics?

    Machine is not coming up with its own ideas working off what was given.

It was basically replicating and supporting my idea. While human collaborator on the other hand was totally unpredictable.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Machine should come up with ideas on its own. Understand the design logic and propose alternative for example build only in one plane if I am doing it in one plane instead of going 3D.

- How different was human collaboration as compared to the machine collaboration?

  Human collaboration was more about getting new ideas from my collaborator. While actions of machine were reflectional on what I have done.

- Were you aiming for a particular design?

  Yes, archway, flat pyramid, aqua duct.

  - Did it change during the collaboration? Yes, In simultaneous case with both human and machine.
  - (if yes)What and who inspired you with new ideas?

    In simultaneous case with human first I was building archway then changed pyramid. And in the simultaneous case with the machine I got the idea of roman aqua ducts.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous; its more interesting to see how machine reacts in real time.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Machine was using the same language as I used, and basically continued my design and sometimes copied it.

  - Did you make use of any visual design principle?

    Not consciously, except symmetry.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible? Yes, Global because it looks at things as whole like humans.

- During human - machine collaboration did you feel you had contributed more to the design?

  Certainly, in terms with new ideas, agent built off them.

- Did you feel that agent was your design partner or a tool?

  Neither of them. But after human-Human collaboration has prompted me to think of it as a partner; Well I guess it was a less independent partner.

  - What features prompted you to think so?

    It wasn't coming up with any new Ideas, except once in the simultaneous case, which made me think of aqua ducts.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    More random inventiveness, as oppose to just respond what's done. Complete randomness would also be good I believe.

C.3 Participant-3

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    It considered my previous steps and aligned with my work as oppose to human who had his own though process.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    Using promptness of the response, design alignment and fast response time.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Machine should also suggest new ideas. I suggest you explore human - human - machine collaboration also, maybe we'll see many new ideas being generated.

- How different was human collaboration as compared to the machine collaboration?

  The design randomness was more with human, machine took steps that was anticipated by me, I knew it was machine, so I made design that it can replicate and learn from.

- Were you aiming for a particular design?

  Yes, partly.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Human, during both the games.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Aligning with thought process, I mean similarity of the design. It was more aligned during simultaneous game.

  - Did you make use of any visual design principle?

    Continuity, proximity, connection and repetition.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes, I think Regional as it was more aligned with my thoughts. In local machine was just copying. And I thought global was a bit misaligned with my thought process.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes. Because, machine was learning my thought process and then doing It, it continued my design, also I started the design.

- Did you feel that agent was your design partner or a tool?

  More of tool than partner; for global and local it was a tool.

  - What features prompted you to think so?

    Copying my move.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    More understanding between the collaborators like both have a common goal they are trying to achieve, having some background or basis for the design. I also believe having more data and training will make it more like a partner.

C.4 Participant-4

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine, with global and regional.

  - Why?

    I can control the machine, it's in my favor that machine works for me without interruption.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    Taking time to get in to action, with human it was fast.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  I would say the speed, the machine lagged.

- How different was human collaboration as compared to the machine collaboration?

The human was a bit confusing and provoking. But, since machine studied my work it was working with me and replicating my design thoughts.

- Were you aiming for a particular design?

  No, not initially but in the second game with human I was.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    With human I started to build architectural framework in the switch game.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous because machine will replicate it in real time.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Try to monitor the work by machine, it was same work but replicated on the other side.

  - Did you make use of any visual design principle?

    Enclosure, continuation and symmetry.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes,In both global and regional. Because I felt machine made some automatic moves by copying mine.

- During human - machine collaboration did you feel you had contributed more

to the design?

Yes, because machine just replicated my structure.

- Did you feel that agent was your design partner or a tool?

  More like a Tool.

  - What features prompted you to think so?

    Replication, even though logic were changed it wasn't coming up anything new.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Work on something different and not copy, so that humans can get new ideas and work with the machine.

C.5 Participant-5

- Did collaboration benefit your design?

  Yes, a lot.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    Made more sense and the design decisions were kind of related. I felt a connection with the collaborator.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    Machine is dumb, the moves of the machine are expected.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Machine should be more intuitive and come up other shapes and forms.

- How different was human collaboration as compared to the machine collaboration?

  Quite different, my thoughts were less influenced by machine, the machine moves were expected. While with human I could see something intriguing being created.

- Were you aiming for a particular design?

  No.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous always.

- Was the contribution by the machine making sense?

  No.

  - How did you decide if the contribution of by the machine, made sense?

    Machine didn't understand me. I thought the machine output was random.

  - Did you make use of any visual design principle?

    Continuity and similarity.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes, Local made more sense, at least it followed me around.

- During human - machine collaboration did you feel you had contributed more to the design?

Yes, it was slow and didn't generate enough input.

- Did you feel that agent was your design partner or a tool?

  Definitely, tool.

  - What features prompted you to think so?

    If you want to replicate something by following your moves the machine can do that.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    More intuitiveness, more randomness and machine should make decisive and deliberate moves.

C.6 Participant-6

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Cannot say prefer, I benefited from both human and machine.

  - Why?

    I felt if I need more authority over my design, I would prefer A.I. And if I want a new design direction, I would prefer human.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  I don't know how you can incorporate this but human I had trust. While with A.I. agent I didn't have it.

- How different was human collaboration as compared to the machine collaboration?

  In human collaboration, it felt like both had authorship and both had contributed to the design. Versus in the case of A.I. I was sole author; it was expanding my Idea. In other words, in human collaboration I felt like two creative entities were working towards something.

- Were you aiming for a particular design?

  Not initially but, I did get ideas after a few moves by the collaborator.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Human, In the switch case I saw the forms the human was making, and I got ideas on how it can be architecturally interpreted and started adding blocks accordingly.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  In terms of creativity I would say simultaneous. In terms of authority and control I prefer switch.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Similarity of forms, I was expecting to see mirroring actions from A.I. and completion of forms I made.

  - Did you make use of any visual design principle?

    Similarity and level of scales.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes, Global and local; I felt like if I wanted to see smaller modifications I would go for local and if I wanted similar strategies on bigger scale, I would go for global.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes, machine was just replicating my moves.

- Did you feel that agent was your design partner or a tool?

  It was design partner.

  - What features prompted you to think so?

    In global settings, I saw behavior that gave me new things, there was a vertical part that agent added horizontal blocks which looked like windows and I started doing the same.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Agent should be crazier, and not just follow I think the degree of attention that the agent is paying to my design can vary and that would result in interesting results.

C.7 Participant-7

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine was fun.

  - Why?

    It was interesting to see how machine understands what I am doing.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    Repetition, similarity, accuracy of pattern recognition and building.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  The sense of design that a human has. The process how different patterns can be merged to form structures.

- How different was human collaboration as compared to the machine collaboration?

  Human had his own design methodologies the final form from the collaboration clearly shows two different methodologies. Machine on the other hand was replicating my thought process creating balanced forms.

- Were you aiming for a particular design?

  Yes.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Human, in both the games, changed what I was thinking like I wasn't thinking of hollow frames when I began. With machine I didn't get new Ideas but the result in the simultaneous game was quite complex.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous it was much more fun.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Pattern replication was the major thing.

  - Did you make use of any visual design principle?

    Proximity, continuity and repetition.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Regional, replication was sensible, and machine was continuing my design.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  Design partner

  - What features prompted you to think so?

    Building and completing the ideas I had, and it felt like completing something together in converging way.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Formation of different geometric pattern, as oppose to copying.

C.8 Participant-8

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    Simultaneous collaboration turned out to be better than I thought.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Not sure, I suppose.

  - If yes, using what features or metrics?

    In human - human collaboration it was more like two people doing their own things. While in human - machine collaboration, the machine was following me and my design thoughts, so that would have prompted me to say it's A.I.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Different point of views and not just copying, so that the composition doesn't turn out be monotonous for some people.

- How different was human collaboration as compared to the machine collaboration?

  In terms of doing the same exercise, I was more excited to see what machine understands and what it was looking at. While in human collaboration I was trying to build my own things and then trying to respond to the other structure.

- Were you aiming for a particular design?

  Yes; staggered design.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    In Human - Machine simultaneous game I was going in one direction, machine picked up another one, and I got influenced and changed my thought to align with the machine.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes, in global scheme.

  - How did you decide if the contribution of by the machine, made sense?

    Because it picked on certain elements that I did, and it carried forward my logic.

  - Did you make use of any visual design principle?

    Emphasis, similarity, continuation.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Global, because it looked at larger cohesive composition, it looked at a bigger picture.

- During human - machine collaboration did you feel you had contributed more to the design?

No, it was equal, but I set up the design and machine picked up, in terms of labor equal in terms of design I contributed more.

- Did you feel that agent was your design partner or a tool?

  Tool.

  - What features prompted you to think so?

    The fact that, machine was following what I did and didn't generate anything entirely new.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Try, a case where machine starts first, I guess it would have been a different experience.

C.9 Participant-9

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    Machine was monitoring my moves and predicting my moves depending on machine learning, it was trained with my previous moves, so it was aligning with my thought process.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No.

  - If yes, using what features or metrics?

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Nothing, it was same in both the cases.

- How different was human collaboration as compared to the machine collaboration?

  Didn't feel any difference.

- Were you aiming for a particular design?

  No.

  - Did it change during the collaboration?

    No.

  - (If yes) What and who inspired you with new ideas?

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Switch/turn taking.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Machine was trying to complete my structure from where I left, it made sense as it followed the same pattern I generated.

  - Did you make use of any visual design principle?

    No, not aware of those principles.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution

most sensible?

Yes. Global, it was monitoring all my moves and had more data to train on and hence was making more sense as it had all the data I had produced.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  Design partner.

  - What features prompted you to think so?

    It was assisting me with same patterns I generate, it was completing my patterns.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Nothing , it was similar in both the cases.

C.10 Participant-10

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    Machine copies my move, with human we can get different results, humans complement with each other.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Maybe Not.

  - If yes, using what features or metrics?

    In simultaneous one its less obvious, but in switch it would have been easier, since machine was following and repeating my moves.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  It was not there even in human collaboration, but it would be good to have "pick your color" and we should be able go below the grid. I guess machine should suggest new ideas.

- How different was human collaboration as compared to the machine collaboration?

  Response time for the human is faster.

- Were you aiming for a particular design?

  No, but towards the end, I was trying to see if machine would follow me.

  - Did it change during the collaboration?

  - (If yes) What and who inspired you with new ideas?

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  More in the switch case.

  - How did you decide if the contribution of by the machine, made sense?

    Continuation, however in switch case we (Human - Machine) were working separately rather than complimenting each other.

  - Did you make use of any visual design principle?

    Not consciously. But I guess similarity, repetition, and continuation are the criteria I considered.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Followed better in local, but regional was making more sense as it was copying better and completing my work.

- During human - machine collaboration did you feel you had contributed more to the design?

  Equal.

- Did you feel that agent was your design partner or a tool?

  Tool.

  - What features prompted you to think so?

    A.I. was doing things that I was doing and was not thinking independently.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    In the local it shouldn't copy recent moves, maybe it can replicate from earlier moves, that I believe would make it would make it seem more human.

C.11 Participant-11

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    In global scenario, I sensed the machine was copying me, so it was like I'll do this part you do the other.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    Obliviously, in human part the other person was thinking independent and we started with our own things and later collaborated, but with machine it was just supporting my work.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Machine should contribute on its own, and not just follow my move and just create symmetry. For example, in human - human case collaborator started doing something entirely different in a different region so that feature should be helpful for human - machine.

- How different was human collaboration as compared to the machine collaboration?

  As I said, machine was basing its move on what I had done. And human had his own idea.

- Were you aiming for a particular design?

  Not exactly.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Human - Human in both games.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Well, if I have a design in mind then it would be easier to decide. I think when I want to monitor the machine move, then I'll use switch, for abstract modelling I would prefer simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    In Global setting, it was mirroring, but in local it was using repetition, so it made sense.

  - Did you make use of any visual design principle?

    Symmetry, enclosure and connection.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Global, I enjoyed it more.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes, in terms of thinking about design.

- Did you feel that agent was your design partner or a tool?

  Design partner in terms of division of labor but largely tool.

  - What features prompted you to think so?

    I could understand the way machine worked in different logic settings, so

I could control the machine to produce exactly/similar what I want.

- What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

  It shouldn't just follow my work, It should make contributions in different part of the grid and later we can merge the idea like it happened in Human - Human

C.12 Participant-12

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Human but it depends.

  - Why?

    In human collaboration, we get another point of view, but with machine collaboration we do not get another perspective.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No not in global or regional but yes in local.

  - If yes, using what features or metrics?

    Because in local mode it was copying all my moves, humans won't do that.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Different design perspective.

- How different was human collaboration as compared to the machine collaboration?

I think the main difference is you control the machine collaboration but can't control the human.

- Were you aiming for a particular design?

  Not at first.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    I was concentrating on filling the region, but later I realized seeing the human that we can concentrate on one region and make 3D structures on different levels.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    In local it was just copying, in global and region it was looking at the overall structure.

  - Did you make use of any visual design principle?

    Mainly Balance/symmetry and occupying the entire area.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Local, because it was copying exactly, so this mode will help in doing repetitive tasks. Maybe during drafting or placing windows, etc.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  For local it was a tool, but for other logics it was more of a design partner.

  - What features prompted you to think so?

    Local it was copying, while in others it was completing.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Its own design perspective and not based on our moves. I think machine should have a personality and its own belief system.

C.13 Participant-13

- Did collaboration benefit your design?

  Yes, in first two.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    I guess we had similar spatial understanding.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    In Human - Machine collaboration, machine was trying to mimic, instead of understanding my thought process and taking it further.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Not just replicating. Machine was just learning from what I was doing. Machine wasn't giving me any new ideas, felt like I was collaborating with myself in mirror instead of separate entities.

- How different was human collaboration as compared to the machine collaboration?

  In human - human I could look at the other person's addition and thinking where I could take it forward. I would want that to be somehow integrated in the machine case as well.

- Were you aiming for a particular design?

  In the switch Human - Machine I was.

  - Did it change during the collaboration?

    Yes, but my thought process changed during human - human collaboration.

  - (If yes) What and who inspired you with new ideas?

    In both the games.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Both have their pros and cons, with switch, I think and see what I want to do, machine would follow. In the simultaneous, its coordinated and I went super random.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

Machine would take my idea further. So, the major indicator was repetition.

- Did you make use of any visual design principle?

  Scales and volumes of spaces. More interested in what is happening because of the addition or subtraction of blocks.

- Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

  Yes. Global, it was able to use the entire grid, machine was trying to bring out my earlier chain of thoughts.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  Less than a partner more than a tool.

  - What features prompted you to think so?

    It was just taking further a thought that I had in mind, it was not provoking me to think again.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Design thinking from another person instead of replicate one person's logic. I suggest have a pair of Human - Machine and interchange machine partners so that it applies its learning from another person.

C.14 Participant-14

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    Human - Human collaboration is a usual thing. It was interesting to find out how machine reacts to different design situations.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  It was difficult to understand, But I think might have.

  - If yes, using what features or metrics?

    Visual similarity and accuracy of what was being produced.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  If it's more responsive like in the case of Human - Human collaboration. And comes up creative answers/models on its own.

- How different was human collaboration as compared to the machine collaboration?

  The only difference was the speed and responsiveness, it's difficult for human to understand the other person's perspective in such short duration of time, and also generate an outcome similar to his, whereas machine is able to do that.

- Were you aiming for a particular design?

  Initially, I wasn't but in simultaneous Human - Machine I tried to come up with a form and realized machine was mimicking my thought process.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Machine, different perspective from machine addition drove my decisions during machine collaboration.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    It was mimicking my thought process and outcome was cohesive and like mine.

  - Did you make use of any visual design principle?

    Connection and proximity.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Global, I felt like it was analyzing my previous responses in the game and basing its move on that.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  Design Partner.

  - What features prompted you to think so?

    Completing and connecting different voxels based on my thought process, very similar to my thought process. So, in a way it can substitute me in doing repetitive work.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Responsiveness, Creative aspect beyond mimicking my thought process, suggesting alternative outcomes.

C.15 Participant-15

- Did collaboration benefit your design?

  Not sure, I wasn't designing anything. In human I was trying to see what human made and tried to connect with their shape.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    Because machine was just copying my steps.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Might not, would like to collaborate with someone who is doing stuff freely and creatively.

  - If yes, using what features or metrics?

    Human developed freely and creatively; machine was copying my steps in a way.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

I don't understand, Human - Machine collaboration, I didn't feel it was collaboration with machine. Machine in my opinion should be little bit independent. Like machine should connect to my shapes.

- How different was human collaboration as compared to the machine collaboration?

  Machine didn't feel like collaboration as it was replicating my moves. But with human I can communicate with the person.

- Were you aiming for a particular design?

  No, just designing freely.

  - Did it change during the collaboration?

  - (If yes) What and who inspired you with new ideas?

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Both can't choose one.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    Because it was seeing my moves and trying to identify what kinds of moves I made and helped me take my steps.

  - Did you make use of any visual design principle?

    No.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution

most sensible?

No.

- During human - machine collaboration did you feel you had contributed more to the design?

  I wasn't doing anything in particular, so not sure about my contribution to the design. But machine contributed to my design by copying my moves.

- Did you feel that agent was your design partner or a tool?

  Design partner.

  - What features prompted you to think so?

    In simultaneous Human - Machine game, I was making one line it added another line beside me, so I changed to think two lines look good.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Not sure.

C.16 Participant-16

- Did collaboration benefit your design?

  Not necessarily, some part yes, some part counterproductive.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    I like interpreting things; I couldn't get sense of what's happening with A.I.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Not sure, probably not.

  - If yes, using what features or metrics?

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  I think, it's more obvious when you are collaborating with human, that interpretation and communication is more salient, Communication is more important for me and its missing from A.I.

- How different was human collaboration as compared to the machine collaboration?

  In this game, switch case with human was quite different as I was trying to interpret what the human was doing, while I couldn't understand what was happening in switch case with the machine. Simultaneous case was no different in both human and machine.

- Were you aiming for a particular design?

  In switch case, I saw human belly and was trying to put legs, for others I just was connecting the structures.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    If it was me, I would make shapes and go from there, but with collaboration a started interpreting what the collaborator was doing.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Switch.

- Was the contribution by the machine making sense?

  No.

  - How did you decide if the contribution of by the machine, made sense?

  - Did you make use of any visual design principle?

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Global, local was the least. Global was less intrusive. Local stopped me clicking a couple of times.

- During human - machine collaboration did you feel you had contributed more to the design?

  Didn't think about it.

- Did you feel that agent was your design partner or a tool?

  In this case design partner.

  - What features prompted you to think so?

    Because, I must interpret what is happening even with A.I. even though I didn't understand what was happening. And with a tool I expect to have complete authority. I can't understand humans.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    I wanted to talk to someone, but that's out of context for the game.

C.17 Participant-17

- Did collaboration benefit your design?

  Yes, humans have different and individual thinking. While machine learns from you.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    Machine was learning from me.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No.

  - If yes, using what features or metrics?

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Machine should start sometimes, so that human can understand what machine can produce.

- How different was human collaboration as compared to the machine collaboration?

  Human from the get-go had different process, innovative and different while machine had no innovation and was following around

- Were you aiming for a particular design?

  Yes, in switch case in both human - human and Human - Machine

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    It completely changed during the human not so much during the machine.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous, it was like race/video game with an unknown user. And much more fun

- Was the contribution by the machine making sense?

  In the switch case it was, in the simultaneous case it was random

  - How did you decide if the contribution of by the machine, made sense?

    Depending on how much it impacted my design I had in my mind initially, in switch it was slowly following me, in the simultaneous case it was random and haphazard, especially when I changed the logic.

  - Did you make use of any visual design principle?

    Similarity, and lot of repetition.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Local was fun as it was like a puppy following me around. Global was unorganized.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes of course, I started it and it was following me.

- Did you feel that agent was your design partner or a tool?

  In switch it was my design partner. Can't say about the other logic.

  - What features prompted you to think so?

    It was following me applying my logic and pattern.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Different approach to the design rather than just copying.

C.18 Participant-18

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Machine.

  - Why?

    It seems, there is as aspect of the unknown. And at the same time copying and replicating sometimes can be better.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    By changing around the logic settings.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  Choice to build off the last block.

- How different was human collaboration as compared to the machine collaboration?

  It was significantly different; computer didn't have an objective and it followed mine

- Were you aiming for a particular design?

  Not as such.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    Human in switch case. For example, I got ideas like connecting in the air and building downward, after seeing the collaborator do that.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    It seemed like there was some kind of connection between what I was doing and what the machine was doing, it was not just random.

  - Did you make use of any visual design principle?

    Continuity.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

Yes. Regional, because it wasn't too close but not too different from my moves, it was roughly close to my design.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes.

- Did you feel that agent was your design partner or a tool?

  Partner.

  - What features prompted you to think so?

    It wasn't a tool since, I wasn't able to control it fully.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    May be machine can somehow not copy mine exactly, but produced something similar.

C.19 Participant-19

- Did collaboration benefit your design?

  No.

  - Who do you prefer human or the machine?

    Machine did better with the local logic. I would prefer human if we were able to talk.

  - Why?

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  Yes.

  - If yes, using what features or metrics?

    If it was on local, I could have, since it was following me precisely. Otherwise it wouldn't have been possible.

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  None.

- How different was human collaboration as compared to the machine collaboration?

  Machine was random, human was trying to make something.

- Were you aiming for a particular design?

  Only once, with the cat face, every other time was just trying to spread the blocks across.

  - Did it change during the collaboration?

    Yes, I ran out of space, If I had more space, I wouldn't have gone up in 3D

  - (If yes) What and who inspired you with new ideas?

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Switch.

- Was the contribution by the machine making sense?

  Not really.

  - How did you decide if the contribution of by the machine, made sense?

  - Did you make use of any visual design principle?

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Local, at least it was trying to build around the block I just placed.

- During human - machine collaboration did you feel you had contributed more to the design?

  Yes, it was supposed to be my design. Since, there was no goal, I set it and I did more towards my goal.

- Did you feel that agent was your design partner or a tool?

  Neither it was like an opponent in a game.

  - What features prompted you to think so?

    Partner would be achieving the same goal, Tool would do what I want it to, but in this case the A.I. was trying to fill up space where I would have, hence an opponent.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    Discuss or set a common goal like make bridges or something and then build it together and machine can come up with different suggestions.

C.20 Participant-20

- Did collaboration benefit your design?

  Yes.

  - Who do you prefer human or the machine?

    Human.

  - Why?

    Human might be able to think in different ways, machine will have a set way.

- If I hadn't mentioned with whom you were collaborating, Could you still differentiate between machine and human collaborator?

  No.

  - If yes, using what features or metrics?

- What features of human - human collaboration would you like to be incorporated in human - machine collaboration?

  No difference.

- How different was human collaboration as compared to the machine collaboration?

  Response time for machine was better than human.

- Were you aiming for a particular design?

  Not sure.

  - Did it change during the collaboration?

    Yes.

  - (If yes) What and who inspired you with new ideas?

    In human - human collaboration in the simultaneous game.

- Which method (switch or simultaneous) would you prefer to engage with the machine?

  Simultaneous.

- Was the contribution by the machine making sense?

  Yes.

  - How did you decide if the contribution of by the machine, made sense?

    It didn't create elsewhere on the grid; it followed my blocks. And it repeated what I had built

  - Did you make use of any visual design principle?

    Symmetry and continuation.

  - Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

    Yes. Global, as it takes into consideration all the moves.

- During human - machine collaboration did you feel you had contributed more to the design?

  I don't know, but design wise I contributed more.

- Did you feel that agent was your design partner or a tool?

  Design Partner.

  - What features prompted you to think so?

    It didn't start creating blocks, it accompanied my blocks and it was a mutual process.

  - What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

    It should accompany other contributor such that the composition is over all symmetrical.

APPENDIX D: POST TASK INTERVIEW - COMPILED DATA

Q1. Did collaboration benefit your design?

Q1a. Who do you prefer human or the machine?

Q1b. Why?

Q2. If I hadn't mentioned with whom you were collaborating? Could you still differentiate between machine and human collaborator?

Q2a. If yes, using what features or metrics?

Q3. What features of human - human collaboration would you like to be incorporated in human -machine collaboration?

Q4. How different was human collaboration as compared to the machine collaboration?

Q5. Were you aiming for a particular design?

Q5a. Did it change during the collaboration?

Q5b. (If yes) What and who inspired you with new ideas?

Q6. Which method (switch or simultaneous) would you prefer to engage with the machine?

Q7. Was the contribution by the machine making sense?

Q7a. How did you decide if the contribution of by the machine, made sense?

Q7b. Did you make use of any visual design principle?

Q7c. Did you modify perceptual logic settings to make more sense of machine contribution? (if yes) In which logic mode was the machine contribution most sensible?

Q8. During human - machine collaboration did you feel you had contributed more to the design?

Q9. Did you feel that agent was your design partner or a tool?

Q9a. What features prompted you to think so?

Q9b. What features from the human - human collaboration should the 'tool' have to make it seem like a partner?

*Grey represents answers of participants who preferred to collaborate with the machine

	Q1	Q1a	Q1b	Q2	Q2a	Q3	Q4	Q5	Q5a	Q5b
P1	Yes	Human	Trust, Similarity	Yes in local	Repetition, Time lag	Not only Mimick, Make random addition	No difference	No	Yes	Human in switch
P2	Yes	Machine	Controll, Predictable	Yes	Mimicking, Repetition	Not only Mimick	Human was giving new ideas; Machine was reflecting	Yes	Yes	Human in Simultaneous; Machine in Simultaneous
P3	Yes	Machine	Alignment	Yes	Fast response; design Alignment	Not only Mimick	Human was random; Machine was reflecting and predictable	Yes	Yes	Human in Simultaneous; Human in switch
P4	Yes	Machine	Controll	Yes	Time lag	Increase speed	Human was provoking; Machine was replicating	Not sure	Yes	Human in switch
P5	Yes	Human	Trust, Inventiveness	Yes	Predictable	Not only Mimick	Human was provoking; Machine was predictable	No	.	.
P6	Yes	Human & Machine	Controll with Machine. Trust, Inventiveness with Human	No	.	Trust	With Human both were authors; With Machine I was sole author	Not sure	Yes	Human in switch
P7	Yes	Machine	Machine Interpretation	Yes	Mimicking, Repetition,Fast response	Not only Mimick	Human was provoking; Machine was replicating	Yes	Yes	Human in Simultaneous; Human in switch
P8	Yes	Machine	Machine Performance	Yes	Mimicking, Repetition	Not only Mimick	Human had own idea; Machine was replicating	Yes	Yes	Machine in Simultaneous
P9	Yes	Machine	Alignment ,Similarity	No	.	Nothing	Same in both	No	No	.
P10	Yes	Human	Human complements	Not Sure	Mimicking, Repetition	Not only Mimick	Human had fast response	No	.	.
P11	Yes	Machine	Mimicking, Similarity	Yes	Mimicking, Supporting	Not only Mimick	Human had own idea; Machine was replicating	Not sure	Yes	Human in Simultaneous; Human in switch
P12	Yes	Human	Inventiveness	Yes	Mimicking in local	Not only Mimick	Machine was controllable; human was not	Not sure	Yes	Human in switch
P13	Yes	Human	Similarity	Yes	Mimicking	Not only Mimick	Human had own idea; Machine was replicating	Yes	Yes	Human in Simultaneous; Human in switch
P14	Yes	Machine	Machine Interpretation	Yes	Mimicking	Not only Mimick	Speed and responsive ness	Yes	Yes	Machine in Simultaneous
P15	Not Sure	Human	Inventiveness	Yes	Mimicking	Not only Mimick	Human had own idea; Machine was replicating	No	.	.
P16	Not Sure	Human	Inventiveness	No	Inventiveness	Couldn't undersatnd	Human had own idea; Machine didn't make sense	Yes	Yes	Human in switch
P17	Yes	Machine	Machine was learning	No	.	Machine should start first	Human had own idea; Machine was replicating	Yes	Yes	Human in switch
P18	Yes	Machine	Mimicking, Similarity	Yes	changing logic setttings	Build from which ever block	Human had own idea; Machine was replicating	Not sure	Yes	Human in switch
P19	No	Human	We can talk.	Yes	Mimicking in local	.	Human had own idea; Machine didn't make sense	Yes	No	Ran out of space
P20	Yes	Human	Inventiveness	No	.	No Difference	Machine had fast response	Not sure	Yes	Human in Simultaneous

	Q6	Q7	Q7a	Q7b	Q7c	Q8	Q9	Q9a	Q9b
P1	Switch	Yes	Mimicked patterns	Symmetry, Continuity, Repetition	Global , Local	Not Sure	More than tool less than partner	logic controls and also regional not clear	Don't create confusions, Give time to designer response
P2	Simultaneous	Yes	Mimicked patterns; Continued patterns	Symmetry	Global	Yes	Less independent partner	Was mimicking; but gave new Ideas	Inventiveness; Randomness
P3	Simultaneous	Yes	Aligned patterns; similar patterns	Proximity, Continuity, Repetition	Regional	Yes	Tool	Was mimicking;	Understanding, work towards common goal
P4	Simultaneous	Yes	Mimicked patterns;	Symmetry, Continuity, Enclosure	Global , Regional	Yes	Tool	Was mimicking;	Not only Mimick
P5	Simultaneous	No	Machine was Random	Symmetry, Continuity	Local	Yes	Tool	Was mimicking;	Inventiveness; Randomness
P6	Simultaneous	Yes	Similar patterns	Symmetry, levels of scales	Global , Local	Yes	Partner	Was mimicking; but gave new Ideas	Inventiveness; Randomness
P7	Simultaneous	Yes	Mimicked patterns;	Proximity, Continuity, Repetition	Regional	Yes	Partner	Was completing my ideas	Not only Mimick
P8	Simultaneous	Yes	Similar patterns	Emphasis, Symmetry, Continuity	Global	Yes	Tool	Was mimicking;	Machine starts first
P9	Switch	Yes	Continued patterns	.	Global	Yes	Partner	Was completing my ideas	Nothing
P10	Simultaneous	Yes	Continued patterns	Similarity, Continuity, Repetition	Regional	Equal	Tool	Was mimicking;	Not only Mimick
P11	Simultaneous for abstract; Switch for control	Yes	Mimicked patterns; Similar patterns	Symmetry, Continuity, Enclosure	Global	Yes	More than tool less than partner	Couldn't control completely	Not only Mimick
P12	Simultaneous	Yes	Mimicked patterns; Similar patterns	Symmetry, Balance	Local	Yes	More than tool less than partner	Was mimicking in local; Was completing my ideas in others	Not only Mimick
P13	Simultaneous for abstract; Switch for reflecting	Yes	Continued patterns;Mimicked patterns	levels of scales	Global	Yes	More than tool less than partner	Was mimicking; Was completing my ideas in others	Not only Mimick
P14	Simultaneous	Yes	Mimicked patterns; Similar patterns	Proximity, Continuity, Repetition	Global	Yes	Partner	Was completing my ideas	Not only Mimick
P15	Both	Yes	Continued patterns;Mimicked patterns	.	.	Not sure	Partner	Was mimicking; but gave new Ideas	Not sure
P16	Switch	No	.	.	Global	Not sure	Partner	Wasn't able to control it.	Want it communicate
P17	Simultaneous	Partly yes	Mimicked patterns; Similar patterns	Similarity, Repetition	Local	Yes	Partner	Was completing my ideas	Not only Mimick
P18	Simultaneous	Yes	Similar patterns	Continuity	Regional	Yes	Partner	Wasn't able to control it.	Not only Mimick
P19	Switch	No	.	.	Local	Yes	Opponent	was competeing with me	Have common goal
P20	Simultaneous	Yes	Continued patterns;Mimicked patterns	Similarity, Continuity, Repetition	Global	Yes	Partner	Was completing my ideas	Not only Mimick