Identifying Game Mechanics for Integrating Fabrication Activities within Existing Digital Games

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ABSTRACT
Integrating fabrication activities into existing video games provides opportunities for players to construct objects from their gameplay and bring the digital content into the physical world. In our prior work, we outlined a framework and developed a toolkit for integrating fabrication activities within existing digital games. Insights from our prior study highlighted the challenge of aligning fabrication mechanics with the existing game mechanics in order to strengthen the player aesthetics.

In this paper, we address this challenge and build on our prior work by adding fabrication components to the Mechanics-Dynamics-Aesthetics (MDA) framework. We use this f-MDA framework to analyze the 47 fabrication events from the prior study. We list the new player-object aesthetics that emerge from integrating the existing game mechanics with fabrication mechanics. We identify connections between these emergent player-object aesthetics and the existing game mechanics. We discuss how designers can use this mapping to identify potential game mechanics for integrating with fabrication activities.

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Figure 1: To help designers integrate fabrication activities within existing games, we use the Mechanics-Dynamics-Aesthetics (MDA) framework and modify it to f-MDA to identify the game mechanics that allow meaningful integration. For example, in the game of Animal Crossing, the game mechanics that allows designing custom clothing can be used to allow the players to physically fabricate their designs and create objects that are associated with their creativity and self-expression.

CCS CONCEPTS
• Human-centered computing → HCI theory, concepts and models.

KEYWORDS
fabrication games, game design framework, physical fabrication

ACM Reference Format:

1 INTRODUCTION:
Fabrication games that combine fabrication activities with a player’s gameplay are an emerging area of research in HCI for their potential to augment the gaming experience in several ways [4]. Objects fabricated from the fabrication games can introduce novel interactions in the gameplay (for example, by fabricating customized game-controllers [19]), teach fabrication skills through gameplay [11, 12, 14], and increase player motivation by bringing the digital content into the physical world [29]. To integrate fabrication activities as part of the gameplay, these fabrication games are typically designed from scratch, which can be a time-consuming process and may require an expertise in game design.
Instead of building games from scratch, in our prior work [27], we presented a framework for modifying existing digital games into fabrication games, by using computer vision to integrate fabrication activities within gameplay moments. We implemented this framework as a toolkit that allows game designers to tag the on-screen visual content of existing game mechanics and integrate it with fabrication mechanics to strengthen the player experience—i.e., the aesthetics using fabrication. Results from the user studies validated the workflow and its potential to augment a myriad of existing games into fabrication games. In particular, understanding the impact of the designer’s choice gameplay moments and its integration with fabrication mechanics on the player’s experience was unexplored.

In this paper, we use the prior study results [27] and further analyze them with the goal of understanding the player experiences emerging from the integration of existing game mechanics [20] and fabrication activities. We first analyze the 47 fabrication events designed by the study participants from the prior study as this study data provides a wide range of example points for the analysis. To analyze these events through its design and technical components, we use the widely cited Mechanics-Dynamics-Aesthetics (MDA) framework [9]. For the analysis, we first modify the MDA framework to F-MDA and incorporate the fabrication components that result from the integration of fabrication activities. We examine each of the 47 events using F-MDA, and identify its corresponding game mechanics, system dynamics, player aesthetics, fabrication mechanics, process of fabrication, and object use.

We found that fabricated objects have the potential to enhance and expand the existing game mechanics in new ways. We noted that the integration led to the emergence of new player-object aesthetics in most cases. We define player-object aesthetics as the emotional associations that the players develop with the objects fabricated from their personal gameplay. For example, a player fabricating a trophy from their winning gameplay could associate it as an object of pride. Our analysis shows the emergence of a set of five new player-object aesthetics (namely, objects of pride, creativity, resource, function, and shared memory) resulting from the fabrication of objects. We map the links between these emergent player-object aesthetics and the existing game mechanics. Designers can use this bidirectional mapping to identify the potential of existing game mechanics to lead to player-object aesthetics and vice versa, and thus integrate fabrication activities with existing digital games.

Contributions: In this paper, we contribute the following:

- We analyze 47 fabrication events using a modified Mechanics-Dynamics-Aesthetics framework (F-MDA) to evaluate how fabrication mechanics can strengthen player aesthetics and introduce new aesthetics.
- We list a set of five player-object aesthetics that emerge out of integration of fabrication mechanics and existing game mechanics. Although non-exhaustive, the list is indicative of opportunities to use fabrication to introduce new player experiences within existing games.
- We provide a bidirectional mapping to link the emergent player-aesthetics with existing game mechanics, that can help to identify the appropriate game mechanics for integrating fabrication activities with existing games.

2 BACKGROUND

2.1 Role of Physical Objects in Digital Games

Creative use of physical objects in digital gameplay can provide the player with a new way of engaging with the game, the environment, and their body. For example, researchers have proposed using physical objects in games to serve as physical game-boards [10] and customized interactive game-controllers [19, 30] in the gameplay. Similarly, in Antle et al. [2], Sonne and Jensen [21, 22] proposed games to help with self-regulation of bodily states during the game play by using physical objects that induce relaxation and calmness. Expanding this concept further to introduce embodied interaction in the gameplay, researchers have also presented frameworks to use wearable controllers [23, 24] and costumes [26] to enhance engagement and narrative immersion. While these physical objects introduce novel interaction modalities and player experiences in the games, these objects are typically pre-designed. To explore the use of physical objects that are not pre-designed, but can be generated from the player’s gameplay, researchers have recently developed fabrication games.

2.2 Fabrication Games

Fabrication games [4] leverage the ability of fabrication tools [3, 7] to allow personal fabrication of complex objects [5, 15] within a fast turnaround time [16, 28]. These games use the fabrication tools either (1) as part of the gameplay, or (2) to fabricate personalized objects from a player’s gameplay. For example, Terraform [25] is a game designed to use a 3D printer in the gameplay to construct physical colonies on a player’s game-board as they expand their territories in the game. Similarly, Threadstading [1] is a strategy game designed to use a computer-controlled embroidery machine to stitch marks over the game-board fabric during a player’s gameplay. While these examples use fabrication tools to indicate a player’s gameplay status, Destructive Games [6] are designed to use a laser-cutter to destroy physical objects in the gameplay so the players can use the destroyed artifacts as conversation starters for social interaction. These fabrication games are typically designed from scratch, which can time-consuming, may need expertise in game design, and it misses out on the potential of using a myriad of existing games that already have a large repository of digital objects and could be fabricated.

We addressed this gap in our recent work [27] by building a toolkit that allows fabricating objects from existing games without needing access to the games source code or expertise in game design. In this paper, we expand on this prior work (detailed in Section 3), by analyzing the results from the prior study in the context of game design, using a game mechanics framework.

2.3 Game Mechanics Framework

While there are several frameworks in the game design literature to examine the player experiences [17], the Mechanics-Dynamics-Aesthetics (MDA) framework [9] is intended for use in creating coherent gameplay experiences through a method of analysis and the deeper understanding of game components. In addition to being one of the most commonly applied and well-known framework, it is used as a tool to describe the design elements: the game mechanics,
A comprehensive list of game mechanics is referenced for integrating fabrication activities with the gameplay of existing digital games. The list is expanded to include mechanics from different perspectives [31], allowing the designers to enhance the players' experience. Researchers have also expanded the list of the components, such as game mechanics [20], to apply it to different contexts. For example, Lim et al. [13], drafted a comprehensive list of game mechanics, which takes into account the game mechanics defined by several researchers [8, 9, 18, 20]. While Lim et al. used this comprehensive list of game mechanics for integration with learning mechanics, our toolkit allows for the adaptation of the MDA framework in the context of integrated fabrication events.

To integrate this fabrication event, designers would first use our toolkit to choose the gameplay moment and integrate fabrication events within the games of their choice. We conducted the study remotely for a duration of 60 minutes over a video call using a Zoom setup. During the study, we first re-briefed the participants on the idea of integrating fabrication events with existing games and then demonstrated the use of our toolkit to tag visual onscreen cues for the integration using a demo example. The participants then used the Zoom's remote control feature to use our toolkit to tag cues within their chosen gameplay moments and integrate fabrication events within the games of their choice. Because our toolkit saved all the information of the events in our directory, for example, the region where Rosalina appears (Figure 2-2c) and generate the event. These tagged visual cues allow our system to locate this gameplay moment using computer vision, during the players' play. Once designers are done tagging cues, they can then export all the fabrication events in a single file (JSON format).

Players can then load this events file in our player interface, use the interface to monitor their screen, and then start playing the game as they normally would. Our system monitors their gameplay using computer vision, scans for tagged cues, and identifies the tagged events using object recognition and text-matching algorithms. Once the fabrication event is identified, the system notifies the player that a fabrication event is encountered. In the player interface, players can access the objects from the encountered events, auto-generate 2D fabrication files (SVG or PNG format) of the objects for laser-cutting or paper-cutting. At this point, players can either continue playing or pause the game to fabricate the object (Figure 2-3). More details about the toolkit implementation and the workflow is described in our prior work [27].
Figure 2: -(1) Our toolkit’s workflow allows designers to integrate fabrication events within existing games and players to fabricate objects from their gameplay. (2) Designers would first use our toolkit’s designer-interface to (a) choose the gameplay moment, (b) tag the visual text or image cue to identify the gameplay moment, and (c) tag the on-screen regions to extract the game objects for fabrication. (3) Players can use the player interface to monitor their gameplay, identify the fabrication events, and generate fabrication files of the game object for (4) fabricating artifacts from their gameplay.

3.3 Study Results:
At the end of the study, the 12 participants altogether integrated fabrication events with 47 gameplay moments within 33 different digital games. These games spanned across several game genres, such as action, adventure, puzzle, etc. The fabricated objects from the integrated events also had a variety of uses from being commemorative trophies and collectibles to being functional gameplay objects, such as maps. Figure 3 shows 8 of the 47 gameplay moments and their respective fabricated objects resulted from the user study. These examples include the following fabricated objects: a customized clothing design for personal collection; a map to help solve the puzzle in the game; a collectible of a war plane destroyed as memorabilia; a custom designed skateboard for personal collection; a rare mask acquired as collectible; and an axe acquired in the inventory as a reminder during gameplay.

A detailed analysis of the results from this study is described in our prior work [27]. Note that the fabrication events were not tested with new participants as players. Rather, our research team simply tested the toolkit’s success rate in generating the 2D fabrication files for laser-cutting the intended objects from the fabrication events resulted from the study.

Beyond the evaluation of the usability of the toolkit, the results and data from this study offer an opportunity to gain deeper insights from a game design perspective on the integration of fabrication activities with existing game mechanics and its resulting player experiences. As this analysis was beyond the scope of the prior work, we analyze them in our current work.
4 METHODS

In this paper, we further analyze and examine the resulted fabrication events from our prior study from the game design perspective. For the analysis, we modify the widely used Mechanics-Dynamics-Aesthetics (MDA) framework and incorporate the fabrication components into the framework. We then use this modified MDA framework (f-MDA) to examine the fabrication events.

4.1 f-MDA Framework for the Analysis

The Mechanics-Dynamics-Aesthetics (MDA) framework [9] allows examining the events through its design components, which are, the game mechanics, the system dynamics, and the player aesthetics. We used the MDA framework for our analysis because it allows us to investigate the fabrication events within the gameplay from both the designer’s and the players’ perspectives. To better understand the impact of the fabrication activities on the game design and the player experience, we first modify the MDA framework by adding the fabrication based components of fabrication mechanics, fabrication process of the objects, before the analysis. The Figure 4 shows the f-MDA framework, that we use to examine each of the 47 events. Within the scope of this paper, we define these components as follows:

**Game Mechanics:** The game mechanics are the algorithmic components and rules of the gameplay. The design of the game mechanics are motivated by what the designer intends their players to experience. To identify the specific game mechanics, we reference the comprehensive list drawn by Lim et al. [13], described in the Section 2.2. This list, that is detailed in Section 5.3 and illustrated in the Figure 7 sorts the myriad of game mechanics based on how they can be used as core building blocks to build game layers, such as, strategy/planning, role playing, rewards/penalties, etc. Consider for example, the game of Animal Crossing (Figure 1) where the player encounters the opportunity to design their own custom clothing. In this gameplay moment, the game mechanic is the system’s ability to update, edit, and customize an existing asset, such as clothing, by modifying the asset’s properties (such as, size, color, patterns, cuts, etc.)

**System Dynamics:** The system dynamics are the run-time behavior of the mechanics acting on player inputs and each others outputs over time [9]. The dynamics are the procedural behaviors of the game’s different parts interacting with each other and the player while the game is being played [31]. In our example of the game Animal Crossing, system dynamics are the interactive features using which the player creates a customized design clothing, chooses their final design, and adds it as a new game asset to the game repository.

**Player Aesthetics:** Player aesthetics are the desirable emotional responses evoked in the player, when she interacts with the game system. The player aesthetics listed by Hunicke et al. [9] in the MDA framework include sensation (game as sense-pleasure), fantasy (game as make-believe), narrative (game as drama), challenge (game as obstacle course), fellowship (game as social framework), discovery (game as uncharted territory), expression (game as self-discovery), and submission (game as pastime). In our example of the Animal Crossing game, the player aesthetics are sensation and expression, as the player experiences joy and discovery during the creative process of designing the clothing.

Figure 3: Examples of gameplay moments from the study that were integrated with fabrication events, and their respective fabrication objects laser cut from the auto-generated fabrication files from the study. (a) In the game Animal Crossing, when the player finishes the custom design of the dress, they can fabricate their final design. (b) In the game Prof. Layton, when the player acquires a map, they can fabricate its physical version. (c) In the game War Thunder, when the player destroys their enemy’s aircraft, they can fabricate the fallen aircraft. (d) In the game Tony Hawk, when the player chooses their custom skateboard, they can fabricate the skateboard design. (e) In the game Skyrim, when the player’s inventory updates with a rare mask, they can fabricate the custom mask. (f) In the game Minecraft, when the player’s inventory of tool is accessed, they can fabricate the tool.
Hunicke et al. [9] explain that from the designer’s perspective, the mechanics give rise to dynamic system behavior, which in turn leads to particular aesthetic experiences. And from the player’s perspective, aesthetics set the tone, which is born out in observable dynamics and eventually, operable mechanics.

**Fabrication Mechanics:** We define the fabrication mechanics as the rules within the gameplay moments that trigger a fabrication event, and nudge the player to fabricate an object from the game. In our example of Animal Crossing, the fabrication mechanics are the rules where as soon as the player adds their custom design as a new asset, the toolkit nudges them to fabricate this new asset with a notification on the bottom corner of their window. Fabrication mechanics can impact the gaming experience based on when the player is asked to fabricate the object and how they are combined with the game mechanics.

**Fabrication of the Object:** This component involves the player using the system to auto-generate and refine the fabrication files of the game object and then fabricating the object using the fabrication tools, such as a laser cutter or a 3D printer to construct the physical object. The player can update the fabrication files based on the choice of the fabrication tool (for example, laser cutting v/s paper cutting) and type of 2D fabrication (cutting v/s engraving). This process can either be automated or require the player input for choosing the material for fabrication, the fabrication tool, and the size of the object. This step also involves assembling the fabricated parts of the object. In our example of the Animal Crossing game, the system auto-generates a SVG file of the custom clothing for laser cutting with engravings of the custom patterns. The player can use this file to lasercut their custom design on a cardboard.

**Object Use:** Once fabricated, the physical objects can offer various uses to the player during the gameplay. The objects could either serve as memorabilia and collectibles, or be useful to progress in the gameplay. For our example of custom designed clothing in the Animal Crossing game, the lasercut clothing can be used as a physical collectible for the player’s personal collection. The object use are important from the designer’s perspectives because if they align with the original aesthetics of the existing game, they could lead to strengthening the player experience.

**Player-Object Aesthetics:** In some cases, integration of the MDA framework components with the fabrication components can lead to emergence of new associations and experiences for the players with the fabricated objects. We define these associations as the player-object aesthetics. From the designer’s perspective, the player-object aesthetics are an important design component because of their potential to add new experiences within the existing games through fabrication. For example, in Animal Crossing, the collectible of the player’s custom designed clothing could be an object of self expression and creativity for the player. Because of this personal association with the object, the player might be motivated to play the game differently. However, if the player-object aesthetics misaligns with the existing player aesthetics it could hinder the player’s gameplay experience. We discuss the types of player-object aesthetics that emerged in the events from the study in the next section.

**5 ANALYSIS**

In this section, we first examine the prior study events using the components of the f-MDA framework. We then describe the new player-object aesthetics that emerge through the integration of fabrication activities with the existing game mechanics. We then identify which existing game mechanics offer the potential to lead to particular player-object aesthetics. From a design perspective, these findings help in identifying and leveraging these game mechanics of existing games for integrating with fabrication activities.
Figure 5: Instances of the 12 out of the 47 events from the study examined using our f-MDA framework. Each event is listed along with its corresponding components of: game mechanics, system dynamics, player aesthetics, fabrication mechanics, fabrication process of the object, object use, and the emergent player-object-aesthetics.

5.1 Examining the Fabrication Events Using the f-MDA Framework:
For examining the fabrication events designed by the participants from the study through the lens of the f-MDA framework, we list the 47 events and their associated components as defined by the f-MDA framework. Figure 5 shows 12 of the 47 events listed along with their game mechanics, system dynamics, player aesthetics, fabrication mechanics, fabrication process of the objects, and the object uses. For the events that lead to new player-object aesthetics, we also list the player’s associations with the objects.

5.2 New Player-Object Aesthetics Resulting from the Integrated Fabrication Events
We observed that several new player-object aesthetics emerged from the integration of fabrication activities with existing games (as shown in Figure 5). While not all encompassing, we observed the following categories of associations that the players would have with their fabricated objects from their gameplay:

Objects of Pride: Designers integrated the fabrication of objects of pride with the game mechanics at special moments within the gameplay, for example, winning the game or acquiring rare assets. The designer’s intent was to allow their players to commemorate their achievements by fabricating and owning these objects that symbolized proud accomplishments. For example, the designer of the fabrication event no 33, where the player could lasercut a dagger shaped object from the game Risk Of Rain 2 said:

"when you collect a very rare or legendary item, for example, this dagger, that occurs only once or twice in the entire game, you can fabricate that, because it is super special" - (p9) [game: Risk Of Rain 2; event no: 35]

Examples of other fabricated objects intended to create pride for the players included 3D printing a prize trophy after winning the race in the game Grand Turismo Sport (p9; event no: 32), lasercutting the dragon mask acquired in the game Skyrim (p3; event no: 15), and lasercutting the winning tiles combination in Mahjong (p5, event no: 19).

Objects of Creativity: Game mechanics that involved player’s input to customize existing assets or create new assets within the game were integrated with fabrication mechanics that resulted on fabrication of the designed objects. Some designer’s posited that because these objects were representative of the player’s creativity and self-expression, the fabrication of these artifacts would influence the player’s gameplay. For example, the designer of the fabrication event no: 16, where the player could lasercut the custom designed clothing from the game Animal Crossing said:
"While there is a million things you can do, there is a [...] feature [...] in the game where you can craft stuff, which [...] would be very fitting for players to fabricate in the real world. So every time, the player crafts an object, they can repeat the fabrication in the real world. I wonder if the ability to craft them in real world will make the players craft them a certain way in the game? " - (p4) [game: Animal Crossing; event no: 16]

Examples of fabricated objects intended to motivate creativity and self-expression among the players included 3D printing tile components of structures (for example, a staircase) built by the players in the game Sims (p5, event no: 20), and lasercutting the skateboard custom designed by the players in the game Tony Hawk (p14, event no: 47)

Object as Resource: Several games are built with the game mechanics of resource management where the players strategically optimize their resources, for example, as currency or as construction material. Designers that integrated fabrication mechanics with such game mechanics intended their players to be more mindful of the limited resource availability. While digital games can theoretically offer infinite resources, in games that use the mechanics of strategic use of limited resources, having physical artifacts that reinforce this limitation can be particularly useful in the gameplay. For example, the designer of the fabrication event no: 7 (Figure 6 left) that allowed players to lasercut a physical coin every time they acquired it in the gameplay said:

"collecting physical coins can motivate players to carefully and smartly use them as currency to [...] to solve the puzzle" - (p2) [game: Prof. Layton & The Curious Village; event no: 7]

Divinity (p11, event no: 41)

Object of Function: Designers also explored the potential of using physical objects that serve the function to support the player’s progress. These objects not only functioned as support objects for the gameplay, but also brought the digital gameplay into the physical world. For example, the designer for the fabrication event no: 8 (Figure 6 right) that allowed the players to lasercut and engrave a map of the village to help solve the puzzle said:

When you load into the game, you get a map, which you can fabricate and that can guide you to the positions you can go to. In the past, we would get a physical map or guides inside the disk case, so this could be something like that, to help with the gameplay" - (p9) [game: Prof. Layton & the Curious Village; event no: 8]

Similar events to fabricate objects of function were integrated were lasercutting maps in the game World of Tanks (p9, event no: 36) and engraving stat-cards while assessing the enemies in the game Final Fantasy (p6, event no: 21, 22, 23)

Object of Shared Memory: In game mechanics that involved multiple users and shared player aesthetics, designers integrated fabrication of objects that the players could associate shared memories with. For example, the designer of the fabrication event no: 3 in the game Crawl with Friends said:

"When several players play against each other in groups, events of wins and losses can be a fun shared experience. It would be cool to have objects from those memorable game events fabricated, for example a board that says ‘Humanity Stolen’ when the boss wins the fight, as a collective memory of an epic win or a painful loss” - (p1) [game: Crawl with Friends; event no: 3, 4]

Similar instances of fabricating objects of shared memory and experiences were designed in other multiplayer challenge games, such
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5.3 Mapping Links between Game Mechanics and the Player-Object Aesthetics

Next, we identify the links between the above mentioned new player-object aesthetics and existing game mechanics. To map these links, we use the same comprehensive list of game mechanics [13] described in the section 3.2. This mapping represented as visual encoding is shown in the Figure 7. The mapping identifies which game mechanics offer the potential of integration of fabrication activities and lead to the five player-object aesthetics that we described in the above section.

This mapping allows us to visualize the links between the game mechanics that have the potential of integrating fabrication of objects with one or more player-object aesthetics. For example, the mechanics of tiles/grids has the potential to integrate the fabrication of objects associated with a player’s resource management, or tool to support gameplay. Conversely, we can also identify the player-object aesthetics that can be most widely applied, for example objects of pride. Using this mapping in the design workflow can support designers in the integration of fabrication activities with the existing games.

Designers can use this mapping in their workflow to integrate fabrication activities with existing games in two ways. First, the designers can analyze the game mechanics of the existing games and look for the potential player-object aesthetics that can be designed with those game mechanics, and then integrate fabrication activities of those objects. Second, the designers with a goal of designing a certain player experience can choose their player-object aesthetic and then identify the list of game mechanics that lead the intended experience. This mapping thus offers a bidirectional design workflow for identifying the game mechanics for integrating fabrication activities with the existing games in ways that either align with the existing player aesthetics, strengthen them, or introduce new aesthetics to enhance player experience.

6 DISCUSSION:
6.1 Implications on the Design of Fabrication Games

The findings from our study highlight five categories of player-object aesthetics that were designed for by participants using our toolkit to integrate fabrication events into existing video games. The five categories demonstrate how the physical nature of the fabricated objects can provide real-time reinforcement of player aesthetics already embedded within the game. For example, providing a physical manifestation of a reward, such as a trophy for
winning a race. Furthermore, the physical objects can also create opportunities to change how certain dynamics are experienced. For example, having physical objects as resources to think with during gameplay such as currency to influence how a player relates to and uses them. Thus, by considering the player-object aesthetics, we demonstrate the breadth of ways in which fabrication events can expand the gameplay of existing video game experiences.

While we described our f-MDA framework and the emergent player-object aesthetics within the scope of modifying existing games into fabrication games, we believe this framework is also relevant to design of fabrication games from scratch. For example, if we were to explore building on Albaugh et al. [1]’s work designing playful textile fabrication games, we could explore the range of player-object aesthetic categories in which embroidered objects may be created and updated. For example, currently the embroidery machine creates the game board as the players explore and gain prestige. Currently, the embroidered object can serve as an Object of Shared Memory and an Object of Pride [1]. However, we could use our framework to explore other player-object aesthetics such as having players embroider their own map or colony during gameplay in order to shift the fabricated textile to also serve as an Object of Creativity.

6.2 Analyzing the Role of Physical Objects in Digital Games

Going beyond the scope of fabrication games, our work can also provide a fresh lens to examine the design space of physical objects, such as controllers used in digital games that do not involve fabrication activities. By analyzing the player-object aesthetics that emerge from the object’s current use and the player experiences, our framework can help identify gaps and opportunities in using physical objects to expand the object’s use and player experiences. For example, examining the design of controllers to expand its use from being objects of function to also being Objects of Pride or Objects of Shared Memory. Furthermore, testing our framework to analyze existing design space of physical and tangible objects in HCI can lead to discovery of new player-object aesthetics. For example, in the game Chillfish [21], that is designed for players with ADHD, the players self-regulate through breathing into the lego controller that uses the player’s biofeedback to control the gameplay. However, because the physical object also induces calmness ad relaxation, the player’s association to the object extends beyond being a game-controller to being an object for mindfulness.

6.3 Limitations and Future Work

The study presented in this paper leveraged existing data on the ways users integrated fabrication events across existing games. In order to gain an understanding for what these moments might mean for a set of players, we analyzed them using the augmented MDA framework. However, we recognize that this is only a first step in understanding the potential gameplay experience; a true understanding of the experience can only be gathered from user testing. Future work will be able to target a subset of cases informed by this work and the mappings that we have developed in order to test the player-aesthetic from players themselves. In order to evaluate if the designed integrated events lead to the intended player-object aesthetics, we plan to conduct more focused studies with various player groups in the future. We also plan to build on this current work and test out the design workflow using the player-object aesthetics mapped with the existing game mechanics.

7 CONCLUSION

In this paper, we expanded on the prior work on integrating fabrication events with existing digital games. We first analyzed the results from the prior study from a game design perspective, using the Mechanics-Dynamics-Aesthetics framework, that we modified to f-MDA to incorporate the fabrication components. For the analysis, we examined the 47 events through the framework components, and observed emergence of new player-object aesthetics in the game, that offer opportunities to use fabrication to design new player experiences. We provided a mapping of the emergent player-object aesthetics with a comprehensive list of existing game mechanics. Designers can use this bidirectional mapping to identify game mechanics for integrating fabrication mechanics within existing games, and thus convert them into fabrication games.

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A FULL ANALYSIS OF THE STUDY RESULTS

For examining the fabrication events designed by the participants from the study through the lens of the f-MDA framework, we list the 47 events and their associated components as defined by the f-MDA framework in the following Fig 8 and the Fig 9.
**Event** | **Game Name** | **Game Mechanics** | **Fabrication Mechanics** | **System Dynamics** | **Fabrication of Object** | **Player Asstulity** | **New Player-Object Relationships Added** | **Object Use** |
---|---|---|---|---|---|---|---|---|
1 | Age Of Mythology | Match ends | collect | fabricate a map of the | game results | laser etch the | discovery, fantasy, experience, narrative challenge, fellowship, fantasy, narrative | object of pride for the players |
2 | Crawl With Friends | Boss fight | capture/eliminate (the | fabricate the avatar of | fight with the enemy | laser etch the avatar of the | laser etch the | object of challenge |
3 | Crawl With Friends | Boss fight lost | capture/eliminate (the | fabricate the avatar of | fight ends, game | laser etch a board with text | laser etch the character | object of pride and shared memory of the game event |
4 | Crawl With Friends | Fight lost, game over | communal discovery (multiple | fabricate a label with the | player ends the | laser etch the | sensation, narrative, challenge, narrative | object of pride of the collective loss |
5 | MarieKart | Rosaltia unlocked | rewards (player docked) | fabricate the avatar of | level ends; player progresses to new level | laser etch the | sensation, challenge, narrative | object of pride |
6 | On And The Blind Forest | Enemy appears for the first time | urgent optimism (immediate) | fabricate the enemy avatar | player follows the enemy | laser etch the | sensation | object as currency for transactions |
7 | Prof. Layton And The Curious Village | Coins received | rewards (coins), resource management (coin used to progress in the game) | coin collection increases that player | player uses the map to further the game | laser etch the physical map | challenge, discovery, narrative | useful for advancing the game |
8 | Prof. Layton And The Curious Village | Puzzle 1: map to solve the puzzle introduced | cascading information (information for game progress), behavioral momentum (player encouraged to explore) | fabricate the physical map | player uses the map to further the game | laser etch the physical map | challenge, discovery, narrative | object as currency for transactions |
9 | Prof. Layton And The Curious Village | Puzzle 6: coin received to help solve the puzzle | rewards (coins), resource management (coin used used to progress in the game) | player uses the coin to progress in the game | player can use the coin in exchange of information/visas | 3D print the coin asset | sensation, resource management, transactions, bartering | object as currency for transactions |
10 | Stardew Valley | Rare game character disappears (the world wonder complete) | prototype effect (player motivated to work harder for the disappeared character) | player brought to the avatar before it disappeared | player introduced to the next challenge | laser etch the | sensation, challenge | object of pride and shared memory of the game event |
11 | Civilization | Creation of world wonder complete | tile laying (expansion of territory, blues) | player brought to the world wonder upon its completion | player can add the monument to the civilization | laser etch the newly added asset | sensation, expression, narrative | object of pride and object of ownership for the players |
12 | Minecraft | New tool added to the inventory (hammer) | rewards (new tool) ability added, resource management | the player can fabricate the tool and a physical inventory | player can use the tool for creation and worldbuilding | laser etch the tool | sensation, expression | object of pride and object of ownership for the players |
13 | Minecraft | New tool added to the inventory (sea) | rewards (new tool) ability added, resource management | the player can fabricate the tool and a physical inventory | player can use the tool for creation and worldbuilding | laser etch the tool | sensation, expression | object of pride and object of ownership for the players |
14 | Skyrim | Dragon mask added to the inventory | collect and rewards | the player can find the mask and the physical inventory | player can use the tool for creation and worldbuilding | laser etch the tool | sensation, expression | object of pride and object of ownership for the players |
15 | Animal Crossing | Crafting workbench acquired | role playing, collecting (games) | the player can fabricate the tool and make a physical inventory | player can use the tool for creation and worldbuilding | laser etch the tool | sensation, expression | object of pride and object of ownership for the players |
16 | Overcooked | Game ends as time is up | time pressure (finishing tasks within time), simulate (kitchen management) | player can fabricate the final game play stage at the end of the match | player ends the game | gameplay state | challenge | object of pride for the players |
17 | Mahjong | Game won | rewards (winning), game turn | player used to fabricate the | player ends the game | winning theme | sensation | remembers the players |
18 | Sims | Structure designed | design/editing, tiles | player used to fabricate the | player progresses in the | 3D print the added asset/structure | expression, sensation, collection of | object of freedom for the players |
19 | Final Fantasy | Assess the enemy | quick feedback | player used to fabricate the | player progresses in the | 3D print the added asset/structure | expression, sensation, collection of | object of freedom for the players |
20 | Final Fantasy | Assess the enemy | quick feedback | player used to fabricate the | player progresses in the | 3D print the added asset/structure | expression, sensation, collection of | object of freedom for the players |
21 | Final Fantasy | Assess the enemy | quick feedback | player used to fabricate the | player progresses in the | 3D print the added asset/structure | expression, sensation, collection of | object of freedom for the players |
22 | Metal Gear Solid | Enemy tagged | role playing | player used to fabricate the | fight continues | laser etch the avatar of the | sensation, narrative, challenge, narrative | object of pride for the players |
23 | Osu | Unique score achieved | rewards (unique score), competitive status | player used to fabricate the | player ends the game | winning score | sensation | remembers the players |
24 | Animal Crossing | Snapper caught | rewards, collecting | player used to fabricate the | player progresses in the | 3D print the added asset/structure | expression, sensation, collection of the captured items | object of pride for the players |
25 | Gira | Color unlocked | rewards (color unlocked), status, behavioral momentum (encourages the player to continue exploring) | player used to fabricate the | player ends the game | graphic scene of the milestone | sensation, discovery, challenge | object of pride for the players |

**Figure 8: Analysis of the 47 study events using the f-MDA framework - part 1**
<table>
<thead>
<tr>
<th>Event ID</th>
<th>Game Name</th>
<th>Power Up</th>
<th>Reward</th>
<th>Player Action</th>
<th>Sensation</th>
<th>Commemorative</th>
<th>Object of Pride</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>p77 Gila</td>
<td>Power unlocked</td>
<td>rewards (color unlocked)</td>
<td>player nudged to fabricate</td>
<td>sensation, discovery, play</td>
<td>object of pride for the players</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>p77 Super Smash Bros</td>
<td>Zelda unlocked</td>
<td>rewards (character available), protege effect, behavioral momentum, resource management</td>
<td>player crossed a milestone</td>
<td>level progression, character introduced</td>
<td>challenge, collectible</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>p88 Astroneer</td>
<td>Reclaim collection</td>
<td>resource management, designing/editing</td>
<td>player can use the resource</td>
<td>resource</td>
<td>challenge, collection</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>p88 League of Legends</td>
<td>Dragon appears</td>
<td>urgent optimism</td>
<td>player crossed a milestone</td>
<td>laser cut the dagger</td>
<td>collectible and memorable</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>p90 Grand Theft Auto</td>
<td>Victory</td>
<td>rewards (character made available), status (new level)</td>
<td>3D print a trophy at the end of the game</td>
<td>sensation, challenge</td>
<td>object of pride</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>p90 Risk Of Rain 2: Ceremonial</td>
<td>Boss appears</td>
<td>cascading information</td>
<td>player crossed a milestone</td>
<td>laser cut the map</td>
<td>object of pride for the players</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>p90 Risk Of Rain 2: Divinity</td>
<td>Battle</td>
<td>capture/eliminate (the monster), role playing</td>
<td>player crossed a milestone</td>
<td>laser cut the dragon</td>
<td>object of challenge</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>p90 Empire Of The Rising Sun</td>
<td>Map Guide</td>
<td>cascading information (information for game progress), behavioral momentum</td>
<td>player uses the map to further the game</td>
<td>laser cut the map</td>
<td>object of function for the player to help them in the gameplay</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>p10 Crusader King</td>
<td>Map of the Territory</td>
<td>cascading information (information for game progress), behavioral momentum (player encouraged to explore)</td>
<td>player uses the map to further the game</td>
<td>laser cut the map</td>
<td>object of function for the player to help them in the gameplay</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>p10 Divinity</td>
<td>Conversation</td>
<td>collecting rewards (new tool added to the inventory), protege effect, cascading information, role playing</td>
<td>player crossed a milestone</td>
<td>laser cut the avatar</td>
<td>object of function for the player to help them in the gameplay</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>p10 Divinity</td>
<td>Crafting</td>
<td>collecting rewards (new tool added to the inventory), protege effect, cascading information, role playing</td>
<td>player crossed a milestone</td>
<td>laser cut the avatar</td>
<td>object of function for the player to help them in the gameplay</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>p10 HOI 4</td>
<td>Map of the Territory</td>
<td>cascading information (information for game progress), behavioral momentum (player encouraged to explore)</td>
<td>player uses the map to further the game</td>
<td>laser cut the map</td>
<td>object of function for the player to help them in the gameplay</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>p10 Age Of Empire</td>
<td>Creation of a building complete</td>
<td>tile laying (expansion of territory), status (level advanced)</td>
<td>player can add the monument to their civilization</td>
<td>laser cut the newly added asset</td>
<td>object of pride for the players</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>p10 Risk Of Rain 2: Crusader King</td>
<td>New achievement unlocked</td>
<td>rewards (new tool added to the inventory), resource management, designing/editing</td>
<td>game continues</td>
<td>disappearing assets</td>
<td>object of pride for the players</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>p10 Risk Of Rain 2: Divinity</td>
<td>Plane destroyed</td>
<td>quick feedback</td>
<td>player crossed a milestone</td>
<td>laser cut the scorecard</td>
<td>object of pride for the players</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>p10 Tony Hawk</td>
<td>Skateboard custom-designed</td>
<td>designing/editing</td>
<td>player used the scorecard</td>
<td>custom-designed skateboard asset</td>
<td>collectible</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9: Analysis of the 47 study events using the f-MDA framework - part 2