A PROCEDURAL APPROACH TO CREATING AMERICAN SECOND EMPIRE HOUSES

A Thesis

by

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ABSTRACT

In this work, we present a procedural approach to capture a variety of appearances of American Second Empire houses, which are well known for their mansard roofs and their inspired ornamentation. To develop this procedural approach, we have identified the set of rules and similarities of Second Empire houses. Our procedural approach, therefore, captures the style differences of Second Empire houses with a relatively few number of parameters. Using our interface, we are able to generate virtual houses in a wide variety of styles of American Second Empire architecture. We have also developed a method to break up these virtual models into slices in order to efficiently and economically 3D print them. Using this method, we have printed miniatures of two landmark buildings in Savannah, GA and Baltimore, MD: The Hamilton-Turner Inn and Enoch Pratt House. We observe that the virtual models still provide more details because of the limited resolution of the 3D printing process.

# DEDICATION

To Matt Justice and my family.

# ACKNOWLEDGMENTS

CONTRIBUTORS AND FUNDING SOURCES

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# 1. INTRODUCTION AND MOTIVATION

Now more than ever, with the rapid progress of our world, digital heritage is an important aspect in the preservation of our cultural heritage [1]. 3D Digitization methods such as shape from shading [9], digitization [21], photogrammetry [32], and laser scanning [34] have been used to bring architecture, monuments, and objects into the 3D virtual space. However, these techniques require these artifacts or houses to still be standing. Reproducing a long-destroyed house in a specific type of architecture is impossible unless one were to create the 3D model by hand.

Manually moving vertices and polygons can result in precisely designed models that reflect the user's intent. However, if multiple variations of one style of architecture are needed, to create each building in the same style but with significant structural and decorative differences would take an immense amount of time. Therefore, there is a need for a method that will allow us to create many models in a rapid and clear manner.

'Procedural modeling' provides a solution to this problem [8]. The term refers to various techniques used to create 3D models based on a set of rules or parameters. The techniques used for procedural modeling can be very broad and encompass techniques such as L-systems, fractals, and other such algorithms [13, 23]. The procedural models are often varied and customized through the changing of specific parameters. One of the advantages of procedural methods is the capability to produce a wide variety of models in a relatively short amount of time [27]. Although the initial tool or program may take some time to complete, the end results are achieved much faster than the time it would take to manually model each version of the desired model. Additionally, changes can be made rapidly, allowing significant ease of control over the model.

One such program that can create these procedural tools is SideFX's Houdini, a node network-based 3D animation software that is known for its visual effects capabilities and ease of procedural modeling [28]. This program is popular in the movie and gaming industry where being able to create a wide variety of easily changeable 3D models is necessary. Despite the power of procedural modeling, the process is not automatic and existing methods do not support all possible styles. For

every style such as Second Empire architecture, there is a need for the development of an associated procedural method by identifying the common features that define that particular style and make it unique.

Second Empire was a popular style of American houses constructed between 1860 and 1880 [14]. Although similar to the Italianate and Gothic Revival styles, Second Empire was considered to be very modern because it imitated the style of French building that was fashionable at the time, making use of the unique Mansard roof, named after French architect François Mansart [19]. The style can be extremely ornate and its potential variety of forms means that many of the houses can look quite different. However, Second Empire's sub-types and architectural rules allow for the identification similarities and common features between the most different of the style's buildings. A person wanting to manually 3D model many variations of Second Empire homes would find themselves facing a monumental challenge in terms of time and effort. There is, therefore, a need for a procedural modeling approach to design a wide variety of Second Empire style houses.

In this paper, we present a procedural modeling approach to easily create and to inexpensively 3D print Second Empire homes. This approach could be used in the field of heritage preservation, or to create models for the film or gaming industry. To demonstrate the power of this approach, we have developed a prototype system and using this system we have created replicas of a variety of Second Empire elements and printed two complete houses. In the rest of the paper, we discuss our process of defining common elements in the Second Empire style and turning those elements into parameters that can be manipulated so a user can create a large variety of buildings with different features. We show examples of homes created with this system, both 3D models and physically printed miniature buildings, and our method for manually breaking up the 3D models so they may be printed at a reasonable price.

## 2.   BACKGROUND AND LITERATURE REVIEW

The procedural generation of architecture and buildings is a well-developed area and many methods have been explored to create detailed and realistic buildings. In 2001, Birch et. al described a range of techniques that would allow historic building styles, from ancient Rome to modern day Hong Kong, to be modeled rapidly and in a way that would limit the feeling of repetition that often plagues procedurally created environments [2]. They used a large library of prototypes and defined building structures through rules and functions to allow users to rapidly create a wide variety of buildings while still constraining the users from creating something that would not be possible in the real world.

Additionally, in 2001, Pascal Müller, along with Yoav Parish, began his extensive work in the field of architectural procedural modeling [20]. In this paper, they proposed a procedural system that made use of L-systems to model city maps, geographical features, and buildings. This system became CityEngine, a 3D modeling software that generates urban environments, although it has also been used for historical and cultural recreations [26].

In 2006, Müller and Wonka continued to develop methods of creating procedural buildings, first by introducing CGA shape [16]. CGA shape is a grammar for the procedural modeling of architecture that creates high detail and quality models at low cost. They illustrated how CGA, along with CityEngine, could be used to create many styles of buildings and included the creation of Pompeii as a specific example. In another paper that same year, they showed how CGA could be used to recreate the architecture of the Puuc style found in the Mayan site of Xkipché, Mexico [15]. In order to do this, they categorized the Puuc building types and general designs in order to develop the sets of rules for their shape grammar.

Other researchers have gone on to use this method of grammar development through categorization and rules [7] [6], including Soon Tee Teoh, who created a procedural modeling system that allows users to alter parameters to create many different buildings in the style of ancient East Asian architecture [31]. In addition to the parameters, Teoh's system allows artists to alter the

appearance of the buildings with "custom-designed geometry [...] such as doors, beams, brackets, roof finials, and roof ridges."

Müller's work has gone into other areas of procedural architectural modeling as well, as seen in his work on the image-based procedural modeling of facades [17] and the interactive procedural modeling of streets [5]. Unfortunately, there exists no procedural approach to handle Second Empire buildings.

## 3. METHODOLOGY



(a) A Photograph of the Hamilton-Turner Inn (1873) in Savannah, GA; Slp1 [CC BY 3.0 (creativecommons.org/licenses/by/3.0)]; Image cropped

(b) A Photograph of the Charles A. Jordan House (1880) in Auburn, ME; Kenneth C. Zirkel [CC BY-SA 3.0 (creativecommons.org/licenses/by-sa/3.0)]; Image cropped

(c) A Photograph of the Pomeroy House (1868) in Southport, CT; Image cropped [11]

Figure 3.1: Photographs of American Second Empire Houses

McAlester and McAlester state that, although similar to the romantic Italianate style, "the Second Empire style was considered very modern," and was named for France's Second Empire during the reign of Napoleon III; among the most notable examples were the additions to the Louvre between 1852-1857 [14]. McAlester also noted that Second Empire architecture was mostly found in the northeast and Midwest of the United States, with less common occurrences on the Pacific Coast and in the South (See Fig 3.1 for examples of American Second Empire houses). It was popular for new constructions as well as remodels because of the functionality of the mansard roof, which allowed for the space of a full upper story. Second Empire was also referred to as the "General Grant Style," as it was very popular for government buildings during President Grant's administration (1869-1877) [25]. After the Panic of 1873 and the following economic depression, the Second Empire style quickly fell out of favor due to its complexity and grandeur [14].

simple mansard roof

asymmetrical

centered wing or gable

towered

town house
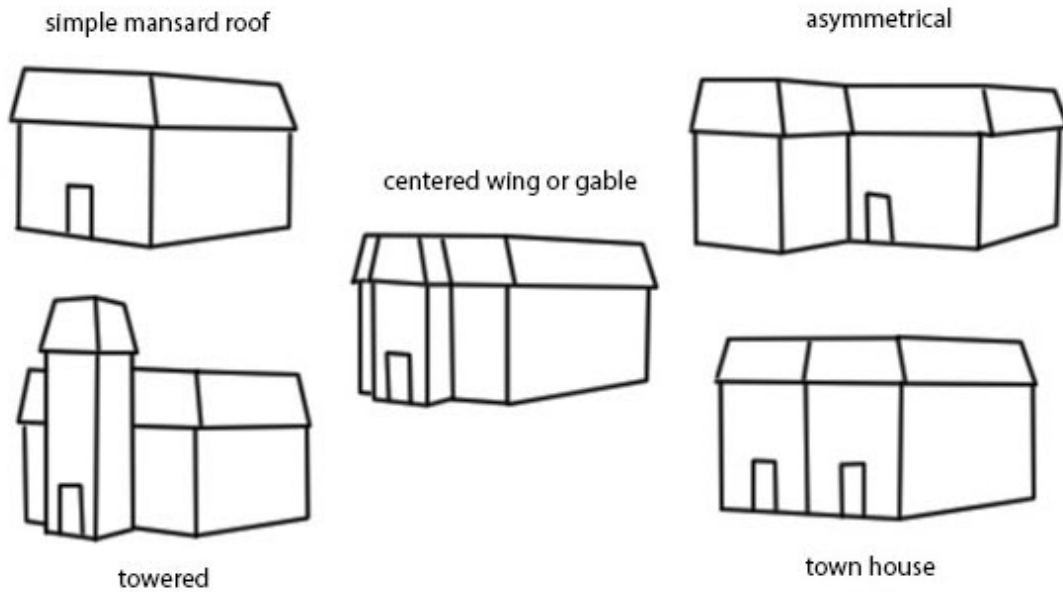
Figure 3.2: Second Empire building types (Based on illustration from McAlester and McAlester [14])

To develop a procedural approach for modeling Second Empire houses, we need to first identify the common features of these houses. We have classified these features into two categories: (1) House and (2) Roof. Within these categories, we have outlined the typical features of these categories as well as their possible additions and elaborations.

## 3.1 House

In this section, we discuss the features of the "House" category: building types, the body of the house, doors, windows, porches, centered wings, and towers.

### 3.1.1 House Sub-Types

McAlester and McAlester [14] describe five principal sub-types of the Second Empire style: Simple Mansard Roof, Centered Wing or Gable, Towered, Town House, and Asymmetrical (See Fig 3.2):

1. **Simple Mansard Roof:** This sub-type is about 20 percent of all Second Empire houses. This sub-type consists of houses that are symmetrical "with the mansard roof uninterrupted

except by dormers."

2. **Centered Wing or Gable:** This type consists of 20 percent of all Second Empire houses. This is similar to the Simple Mansard Roof "but [these houses] have either a centered gable... or a mansard-roof extension or wing centered on the front wall."

3. **Towered:** This sub-type comprises about 30 percent of Second Empire houses. The tower "[s]ometimes [...] occupies the position where the wing joins the principal section of an L-plan house, but is more commonly centered on the front facade."

4. **Asymmetrical:** This sub-type comprises about another 20 percent of Second Empire houses. "These are compound-plan houses, usually L-shaped, which lack towers." This work will not be focusing on the asymmetrical styles of houses.

5. **Town House:** This sub-type was a central style in urban housing between 1860 and 1880. It utilized the mansard roof to allow for "the structure [of the buildings] to appear less massive than most other styles with comparable interior space." While this work is capable of creating models that resemble a Second Empire Town House, it was not a central focus.

### 3.1.2 Body

The main body of a Second Empire house, before any additions such as towers or centered wings, is often square or rectangular in shape [14]. We have also observed that these houses typically have one to three stories (not counting the mansard roof), with two stories being the most common. Decorations such as a belt course, a continuous row of bricks in a wall, may be found on the houses, as well as quoins, decorative blocks at the corners of walls [30, 4].

### 3.1.3 Doors

Second Empire doors were often paired or single [14]. They were typically ornate and appeared in the same shapes as the windows.

### 3.1.4  Windows

The windows found on Second Empire houses are similar to that of the Italianate style [14]. Windows are frequently paired or tripled. Tops of windows are typically rectangular, arched, or curved, and have decorated surrounds that may feature brackets. In addition, we have observed that the fronts of the houses typically have five or less windows. Second Empire windows differ in one way from the Italianate style in that unelaborated and arched windows are common [14]. The windows may also have decorative iron faux balconies.

Bay windows also may be present and we have observed that they are typically one or two stories. Additionally, we have noted that occasionally they are only on the second floor of a house, allowing room for a porch below. They also may have a small roof or, if the bay window is the same height as the house, may have a large roof that incorporates itself into the mansard roof and even has its own dormer window.

### 3.1.5  Porch

Porches were very common and important to the Second Empire style. They often were found on the front of the house (either small for the entry or the full width of the house), wrapped around the house, or on the sides of the houses. The porches were one-storied and occasionally featured a decorative balcony on top. Many of the posts were square in style and had typically simple balusters [18].

### 3.1.6  Centered Wing

Centered Wings appear on the front of Second Empire houses. They typically feature the same windows as the body of the houses, although we have observed examples where both the window and dormer on the wing are more elaborated. Much like the body of the house, we have noted that the wing may also have quoins as a decoration. The wing may encompass the entirety of the stories of the house or may exclude the first floor in order to make room for a porch. Examples of a Second Empire house with a centered wing can be seen in Fig 3.1c in the Pomeroy House.

### 3.1.7 Tower

As stated before, Second Empire houses with towers make up 30 percent of all Second Empire houses. In asymmetric building types, the tower may be placed "where the wing joins the principal section of an L-plan house, but it is more commonly centered on the front facade" [14]. The tower may be square or rectangular in shape, and usually projects from the house. A tower also typically is a floor or two higher than that of the house [19]. Tower roofs may have a different roof silhouette than the roof of the main house, and they often feature the less common roof shapes [14]. Dormers are also typically present on the tower's roof. Like the centered wing, we have observed that the tower may encompass the entirety of the floors of the house or may take up all but the first floor in order to accommodate a porch. An example of a towered house can be seen in Fig 3.1b.



straight    straight-flare    concave    convex    s-curve 1    s-curve 2
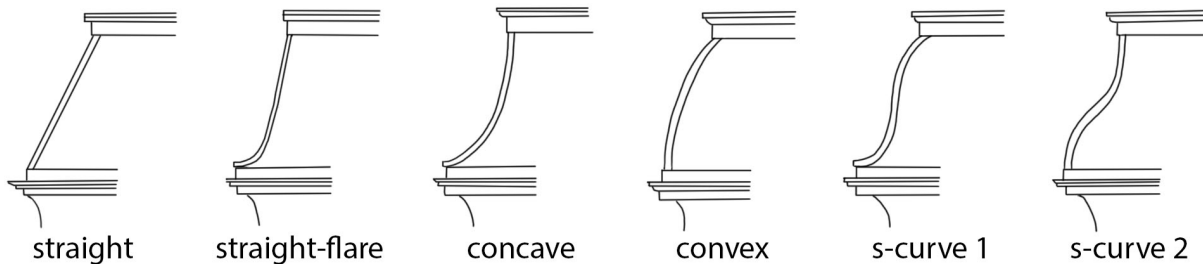
Figure 3.3: Second Empire roof shapes (Based on illustration from McAlester and McAlester [14])

### 3.2 Roof

In this section, we detail the features of the "Roof" category: roof designs, dormers, cornices, brackets, cresting, chimneys, and centered gables.

### 3.2.1 Roof Designs

The most distinctive feature of a Second Empire home is its mansard roof, which is dual-pitched and hipped [14]. The top of the roof may also be flat. As stated in A Field Guide to American Houses, the roof has five principal silhouettes - straight, straight with flare, concave,

convex, and S-curved; the first three are very common while the last two are very unusual to see on the main roof of the houses, although they are more common on tower roofs (See Fig 3.3).



Figure 3.4: Examples of dormer window shapes

### 3.2.2 Dormers

Dormers, a roofed structure that sticks out vertically from pitched roofs, and dormer windows are also present on the roof, and exist in a wide variety of styles (See Fig 3.4)[3, 14].



Figure 3.5: Examples of typical cornices and brackets (Based on illustration from McAlester and McAlester [14])

### 3.2.3  Cornices

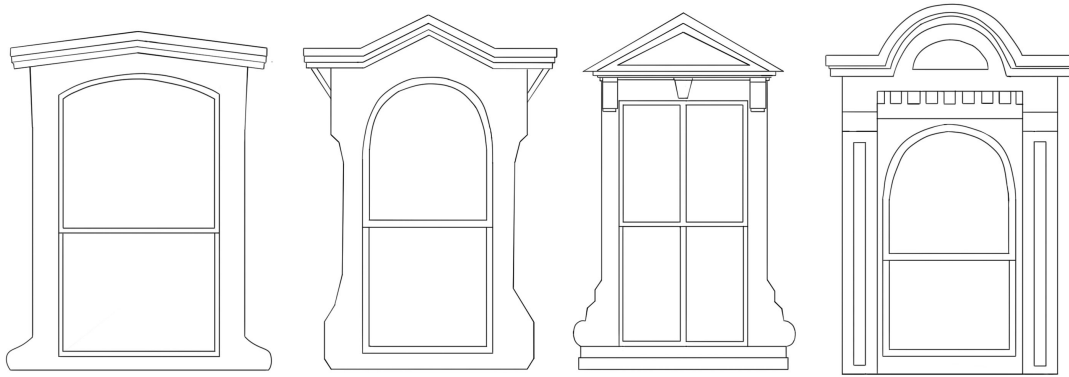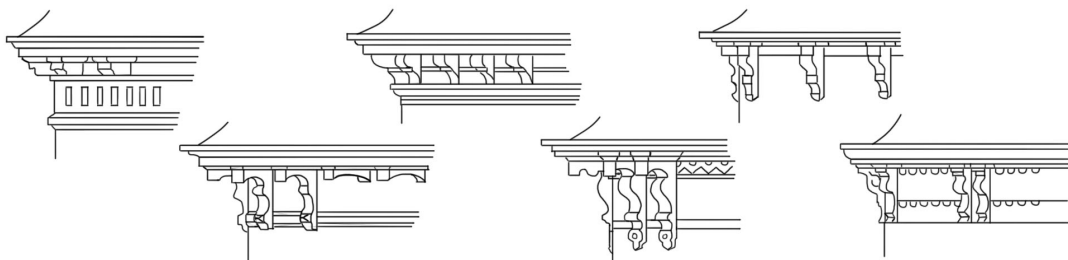At the top and bottom of the mansard roofs are cornices or "French curbs" [19]. Underneath the bottom cornices are often elaborate brackets, and the upper cornices were often decorated with iron cresting. The cornices exist in an "almost infinite variety of shapes and spacings" (See Fig 3.5)[14].

### 3.2.4  Brackets

Italianate brackets, found underneath the bottom cornices, are a very common feature of Second Empire houses, although they are not found on every house [14]. They are either single or paired and appear in a large variety of styles (See Fig  3.5). We have observed that the brackets also appear on centered wings, towers, and occasionally porches and bay windows.

### 3.2.5  Cresting

Iron cresting can be found on the roof tops of Second Empire houses, although they have deteriorated on most of the houses still standing today [19].

### 3.2.6  Chimneys

As noted through our observations, Second Empire houses may feature chimneys on the top of the mansard roof or on the sides, next to the dormers. Chimneys on the sides of the mansard roofs often appear in pairs that are either between the dormers or on either side of them.

### 3.2.7  Centered Gable

Centered gables often echo the silhouette of the mansard roof of the house [14]. A window the same as the dormer windows of the roof is often present in the middle of the space created by the centered gable.
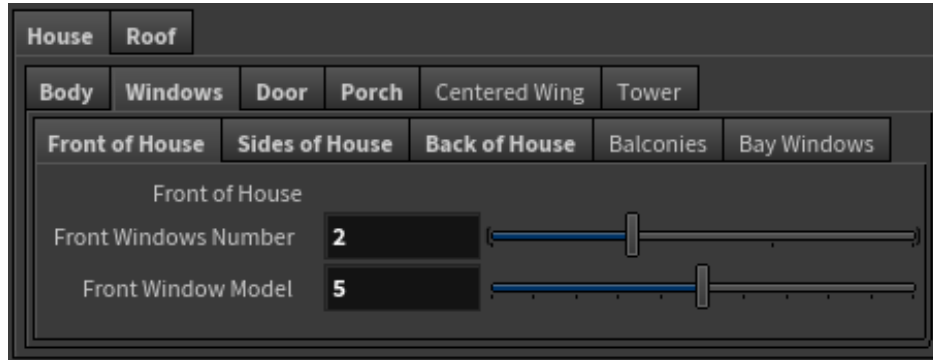
Figure 4.1: Interface of our procedural tool and example of the parameters used to modify the house model

## 4.1 Software

We have implemented our computational methodology as a digital asset through Houdini. Houdini's node networks can be turned into a reusable custom node, a Houdini digital asset (HDA), with its own user interface to allow for the controlling of parameters. Houdini also allows for the use of VEX code, "a high-performance expression language that can be used in several areas, including modeling, allowing "custom surface node[s] that manipulat[e] point attributes" [29].

Houdini allows for the creator of an HDA to set a custom user interface. The creator can decide which parameters to expose and can organize the parameters with labels, tabs, etc. in order to create a simple and direct experience for the user. For our HDA, we made sure to organize the interface in such a way that a user would easily know what they are doing to the model. Similar to our analysis of the Second Empire style, the sections of the parameters are split into "House" and "Roof", and in each of these sections contain sections for the more specific attributes of the houses (See Fig 4.1 for example of our user interface). Certain parameters are also hidden until a qualifying parameter has been toggled on; for instance, you cannot see the placement parameters

for balconies unless the user has checked the toggle for balconies. This minimizes the visual mess of the interface by only showing parameters that are necessary and currently needed.

The parameters allow for complete customization of the house, although exceptions have been made for instances where combinations of parameters would not be realistic. For example, a user cannot put a door and a window in the same spot, or a tower and a centered wing cannot exist on the house at the same time. This keeps the user in check while still allowing them a wide range of possibilities. We chose to allow the user to pick their desired combination of features rather than force them to choose combinations that would be likely in real-life Second Empire houses.

## 4.2    Procedural System

### 4.2.1    House

#### 4.2.1.1    Body

With the body of the house, the two most obvious parameters are the size of the house and the number of floors. The user is able to change both the length and the width of the house. The user is also allowed to change the house to be between one and three floors, as we have observed that most Second Empire Homes do not go above three floors. Changing the number of floors causes the tool to switch between three models, each with the corresponding number of floors. The user also has the option to include quoins and belt courses, and may choose between multiple styles.

#### 4.2.1.2    Windows

The windows may be altered by choosing the number of windows on both the front and the sides of the house, along with an option to have different numbers of windows on the first and upper floors of the sides of the house. If the house has more than one story, the first floor will have the number of windows chosen, while the second floor will have this number plus one more to account for the absence of a door. On the sides of the house, the user may move the position of the side windows or bring the side windows closer together. Windows will also not appear in spots that are taken up by doors, towers, centered wings, or bay windows. Multiple window models are available for the user to choose from.
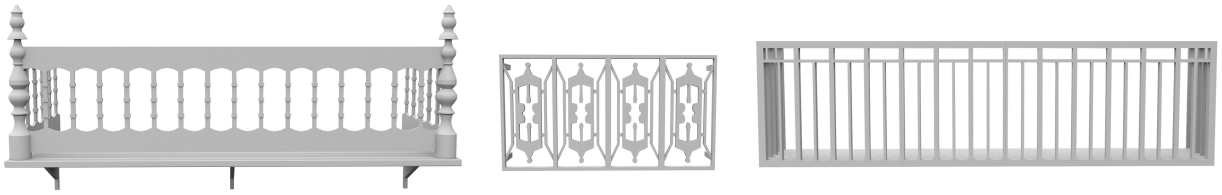
Figure 4.2: Renders of balcony styles

### 4.2.1.3    Balconies

Balconies are another ornamental aspect that may be added to the front, left, and right sides of the house (See Fig 4.2). The number of balconies is independent for each floor for maximum customization. If the number of balconies is less than the number of windows, the balcony position may be changed independently for each floor.



(a) Example of a bay window

(b) Examples of door styles

Figure 4.3: Renders of a bay window and multiple door styles

### 4.2.1.4    Bay Windows

The tool also allows for the inclusion of bay windows, a beautiful detail that appears on many Second Empire houses (See Fig 4.3a). The user has a choice to place bay windows on the front, left, and right side of the house. The placement of the bay window may be changed and will match

the areas where the regular windows are present. The bay window may occupy the first floor, the first and second floor, or only the second floor. On the front of the house, the depth and width of the bay windows may be altered, and the side windows' angles can be adjusted to fit the new depth and width. Roofs may be added to the bay window, and the user can switch between a large and small roof. The large roof changes its appearance to match the shape of the house's roof. Small roofs may also be added between floor sections on the bay windows.

### 4.2.1.5  Doors

Next is another always-present feature - the door. The position of the door may be changed and the windows move to accommodate the position, making sure that the door and a window do not overlap. The user is able to pick from multiple models for the door (See Fig 4.3b).

Stairs leading to the front door are also present on the front of the house. The user is able to control the number of steps, length, height, width, table length, and handrails. The stairs are always located in front of the door, and they adjust position based on the presence of a centered wing, tower, or porch. The user is able to choose whether the handrails are present on one, both, or neither sides of the stairs, and may choose from various models for the look of the handrails.

### 4.2.1.6  Porch

Porches are a common feature on many Second Empire houses. In our procedural tool, porches are optional and multiple choices for style and placement of the porches are provided. The user may utilize a front porch, side porch, wrap around porch, or a one-sided wrap around porch (See Fig 4.4). Once the front porch is switched on, many parameters become visible that allow the user a good amount of customization. The user is able to change the size of the porch by extending it to the right or left. This, instead of a symmetrical scaling system, allows for greater control. The user is also able to increase and decrease the depth of the porch. Additionally, the user may decrease or increase the amount of posts present on the porch. The number of posts will also automatically decrease or increase if the user makes the porch larger or smaller. Porch railings are also optional and have multiple models that the user may choose from to fully customize the porch. The railings

Figure 4.4: Top row: Renders of examples of the front porch and side porch; Bottom row: Renders of examples of the wrap around porches

are also set up in a way that make it impossible for the railing to be placed in front of the front door. Along with an option to exclude the porch top model, and additionally the posts, the user is able to add an extended front section to the porch. This extended section has the same parameters as the main front porch and can independently change in depth and extend left or right. When the front porch is enabled, the wraparound porch switch is hidden so the user cannot have overlapping porches. The user may also enable a balcony on the top of the porch, effectively creating railings on the top of the porch as well as the bottom.

The user is able to create a porch on either side of the house. Many of the parameters are similar to the previous porch sections, including side of the house placement, depth, post frequency, and extending left or right (or back or front, in this case). The side porch also creates a door and stairs on the side of the house, and the user is similarly able to pick the position of the door. The user may also choose to have stairs on the back side of the porch instead of directly in front of the door.

Lastly, the user is able to create a wrap around porch that occupies the front, left, and right sides of the house. They are able to change the amount of posts and switch the porch railings on or off. Similarly, the user can enable a porch that occupies the front and only one side of the house. The user is able to choose whether the "one side" is the left or right side of the house. The other parameters are the same as the wrap around porch.

### 4.2.1.7   Centered Wing

In our tool, the user is able to switch on or off a centered wing in the middle of the house and then make adjustments to its appearance (See Fig 4.5a). Because many, but not all, of the houses have porches, the option is given to exclude the first floor of the centered wing. Toggling this on simply switches the model to one without the base or first floor of the wing, creating space for a porch. Like the main roof parameters, the roof shape of the centered wing roof may be changed into any of the five shapes. The height of the roof is also adjustable, as some houses have taller centered wing roofs than their main roof. Additionally, the depth and width of the centered wing are also adjustable and, when changed, affect the roof accordingly. The brackets and cresting of the centered wing are also optional, and different models are available for the user to choose from.

The user is also able to enable quoins on the centered wing, much like on the main part of the house.



(a) Example of a house with a centered wing

(b) Example of a four story tower on a three story house

Figure 4.5: Renders of a centered wing and tower

### 4.2.1.8 Tower

Much like the centered wing, the tower has the option to exclude the first floor in order to allow for a porch or other extrusion. The number of floors the tower has is changeable, as many houses had towers one or more floors taller than the main house (See Fig 4.5b). The user is able to change the tower's width and length, as well as the position of the tower, as some towers may stick out more from the house than others. The height of the tower is also somewhat adjustable, as the user may want the tower roof to be farther away from the roof of the house. Once again, the tower roof may be changed to any of the five roof shapes. Brackets and cresting are also optional. One major difference in the tower versus the centered wing is the option to include windows on the sides of the tower.
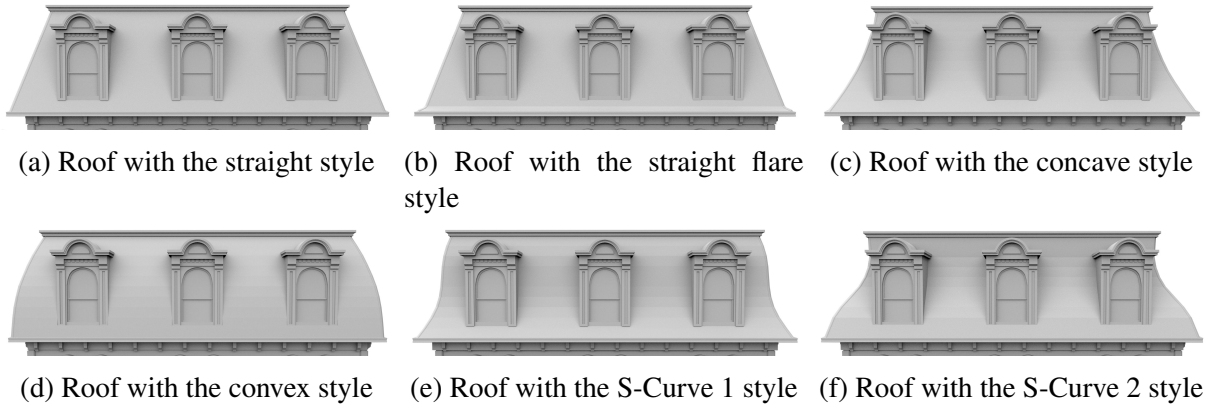
(a) Roof with the straight style    (b) Roof with the straight flare style    (c) Roof with the concave style

(d) Roof with the convex style    (e) Roof with the S-Curve 1 style    (f) Roof with the S-Curve 2 style

Figure 4.6: Renders of roof shapes

### 4.2.2 Roof

#### 4.2.2.1 Roof Design

As discussed previously, there are five different roof shapes for Second Empire houses, and the user is able to choose one of six shapes (all five along with another variation of the s-curve), which then causes a switch between models inside of the tool (See Fig 4.6).



Figure 4.7: Renders of examples of dormer styles and placements
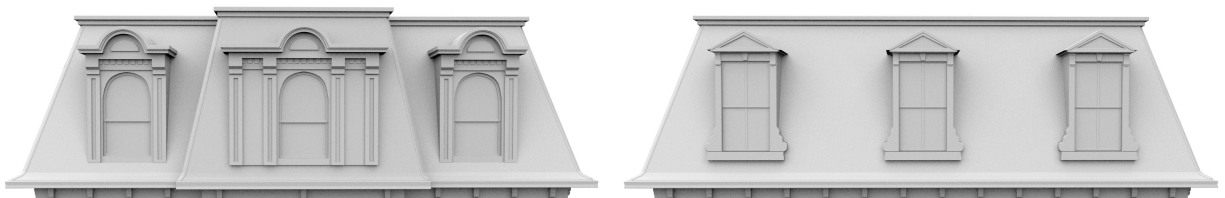
#### 4.2.2.2 Dormers

The dormers are also very central to this tool, as every Second Empire house has at least one dormer window on its roof. The user is able to control the number of dormers present on the front and side of the house, and may also change the dormer model (See Fig 4.7). The dormer windows may also be moved closer to or farther away from each other.

### 4.2.2.3  Cornices

The cornices at the top and bottom of the mansard roofs are always present and may be switched between a variety of styles.
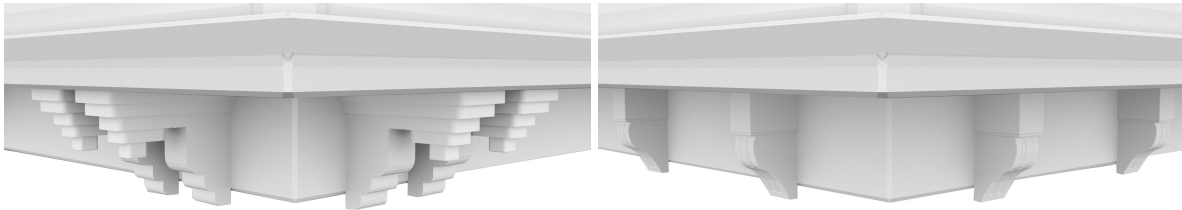


Figure 4.8: Renders of two bracket styles

### 4.2.2.4  Brackets

Brackets are an optional component, as most but not all Second Empire houses have them, and may be switched on and off. The users may control the spacing between the brackets to have fewer and farther apart or greater and closer together brackets. Multiple bracket models are also available (See Fig 4.8).
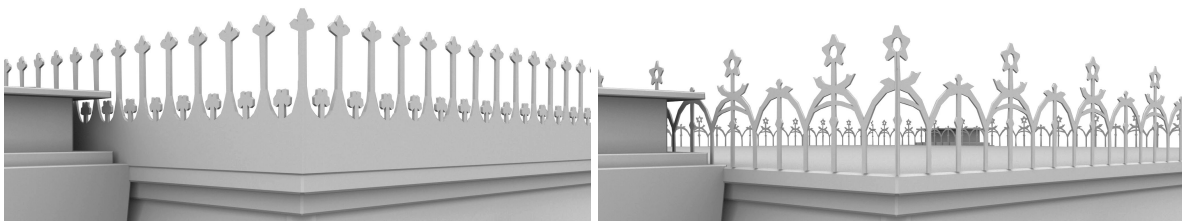


Figure 4.9: Renders of two cresting styles

### 4.2.2.5  Cresting

The next optional roof detail is the cresting. When this is switched on, the user may control the space between the cresting, much like the brackets. However, this will most likely only need

to be used when switching between cresting models, as most people would not want gaps between sections of cresting. The cresting also changes its location depending on the presence of a tower, centered wing, centered gable, or chimneys, so as to not intersect with any of the models. The user also has the option to choose between multiple cresting models (See Fig 4.9).



Figure 4.10: Renders of side chimneys and top of the roof chimneys

#### 4.2.2.6 *Chimney*

Another element present on the roof is the chimney. The user may include chimneys on the top part of the roof, on the side of the roof, or both (See Fig 4.10). The tool allows for up to two chimneys on the top of the roof. The user can then choose the position for both chimneys. The sides of the roof can have chimneys on the left side, right side, or both, and may have between one or two chimneys. Much like the side windows, the user may move a single chimney's position or bring two chimneys closer together or farther apart.
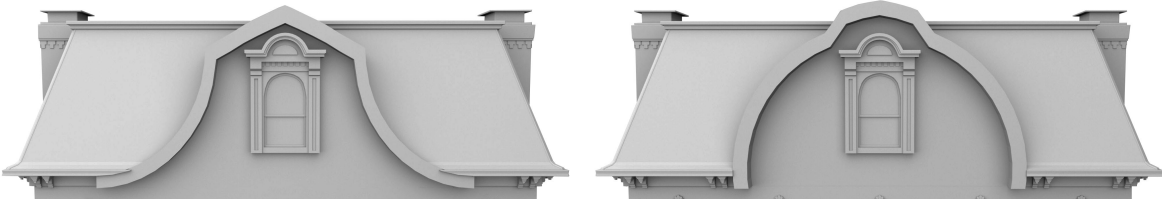


Figure 4.11: Renders of two styles of centered gable

The options for the centered gable are simple - the user is only able to enable the centered gable and pick between styles (See Fig 4.11).
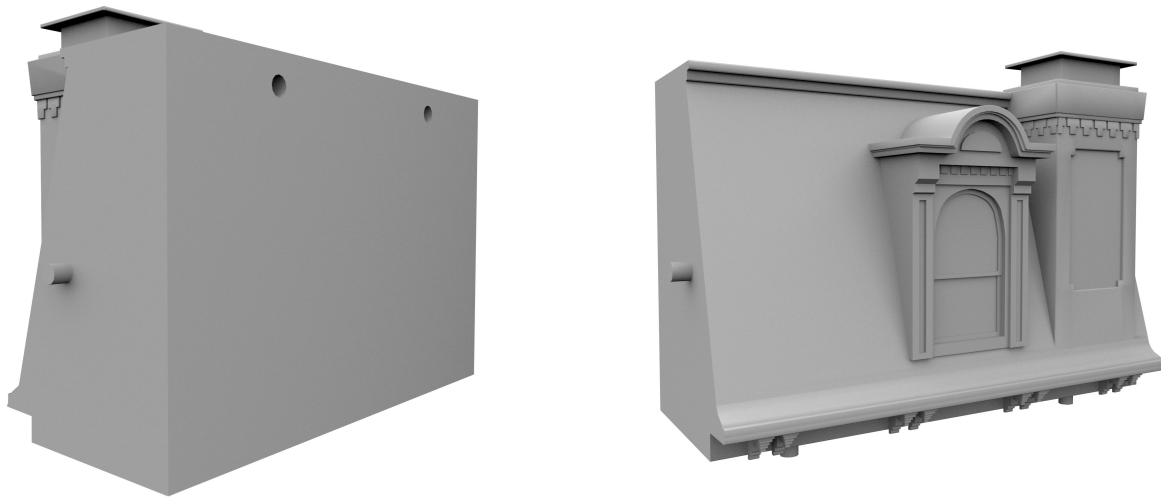
## 4.2.3  3D Printing



Figure 4.12: Renders of a slice of the roof and the pin and cavity method

Our goal through the 3D printing of these houses was provide a visual aid of Second Empire houses and to develop a method that would allow us to print at a more cost-effective price than the cost of printing an entire house altogether, which would be very costly. In order to do this, we decided that breaking the houses up into sections would be best, as less area that the printer had to move around in would mean less cost (See Fig 4.12). Using the Hamilton-Turner Inn model as an example, we will describe the process we went through to break up and print the 3D models. In order to print relatively flat, we needed to break up the model into pieces that would be the most economical to print but would still make sense for putting the house back together afterward. Therefore, the most obvious place to start was breaking the body of the house into the separate

walls. To achieve this, we used a Boolean node to subtract the portion of the base of the house that we did not want in the print piece, leaving behind, for example, the front wall with enough thickness behind it to accommodate for the depth of the front door. This was done for all four walls so each became its own separate piece. Although features such as the bay window and centered wing are technically part of the wall, they were removed and made into their own separate print pieces in order to further try to cut down on cost. This was done by simply separating the models from the base of the house.

The four side roof pieces were also created through the same boolean process, although careful consideration was made in placing the break-points to ensure that the dormers would not be cut in half. The top of the roof was also made into a separate thin piece because the side roof pieces left a gap in the middle when assembled. The roofs could have been broken up more, perhaps with the dormers as separate pieces as well, but they were kept whole in order to create an easier assembly process in the end.

The porch was broken up by separating the models from each other. The only portion of the model that stayed together for the printing process was the porch posts and railing, as the railing seemed too small to separate and would cause difficulties in assembly later. The top and bottom of the porch were separated into different pieces as well as the stairs and stair handrails.

In order to connect all of these pieces after printing, we decided to use the pin and cavity method. "The pin and cavity helps to hold parts together by increasing friction, adds extra surface area for adhesives, and improves the alignment of separate components" [22]. In order to make sure the fit of the parts was snug without being too tight, the cavity was created to be .125mm larger than the pin. At the intersection spot of any two of the print pieces, we created two pin and cavity spots. With two interlocking spots, the print pieces are less likely to rotate out of position. So, for example, the front wall has two pins and eight cavities - two pins to connect to the front roof and two cavities each for the left wall, right wall, centered wing, and porch bottom connections. When deciding whether a spot would have a pin or a cavity, we took into account the projected print direction and what would be the easiest when assembling the entire house.

# 5. RESULTS

## 5.1 Procedural Models

Using our classification of features and subsequent procedural method, we are able to generate many styles and variations of Second Empire houses. By controlling the parameters, we are able to quickly change the appearance of the 3D model. The following renders (created in Autodesk Maya using Pixar's Renderman) are examples of the models of the Hamilton-Turner Inn [33] and Enoch Pratt House [12] that we have created using our procedural tool (See Fig 5.1, 5.2).



(a) 3D model of the Hamilton-Turner Inn



(b) Details of the 3D model of the Hamilton-Turner Inn

Figure 5.1: Renders of our 3D model of the Hamilton-Turner Inn created using our procedural system

## 5.2 3D Prints

Using our proposed method for 3D printing, we were able to create 3D prints of both the 3D models of the Hamilton-Turner Inn (See Fig 3.1a) and the Enoch Pratt house (See Fig 5.4 for photos of the prints). The prints, although still not inexpensive, were cheaper and of a better visual quality when printed in the slices than as the whole model of the house (See Fig 5.3 for images of

(a) 3D model of the Enoch Pratt House
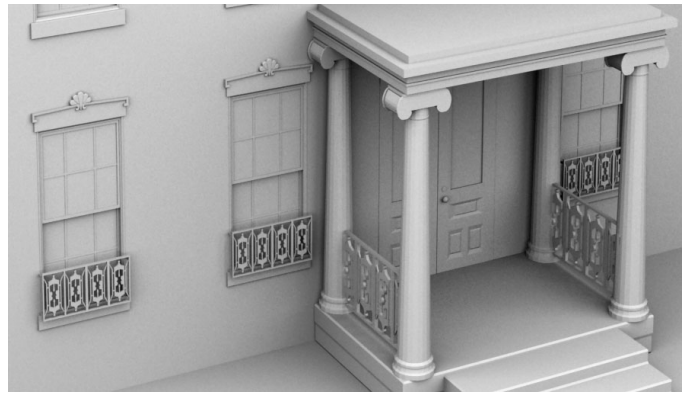


(b) Details of the 3D model of the Enoch Pratt House

Figure 5.2: Renders of our 3D model of the Enoch Pratt House created using our procedural system

the sliced prints). We additionally used the cheapest plastic material available to us for printing. However, because of the size of print we were able to make, the smaller details such as the crestings and balconies were unable to be printed (See Fig 5.5). In the case of the Enoch Pratt House, even the porch posts could not be printed due to their shape and size. Some details on the model also had to be altered in order to be printable at a reasonable quality. Additionally, at the size we printed at, the printer was not precise enough to print the pins and cavities in a consistent manner. We therefore had to simply glue the pieces together, as the pieces would either not join together at all or were too tight of a fit. Once pieced together, we coated the models with a gray primer to make the color uniform and help to fill in any gaps in the models.
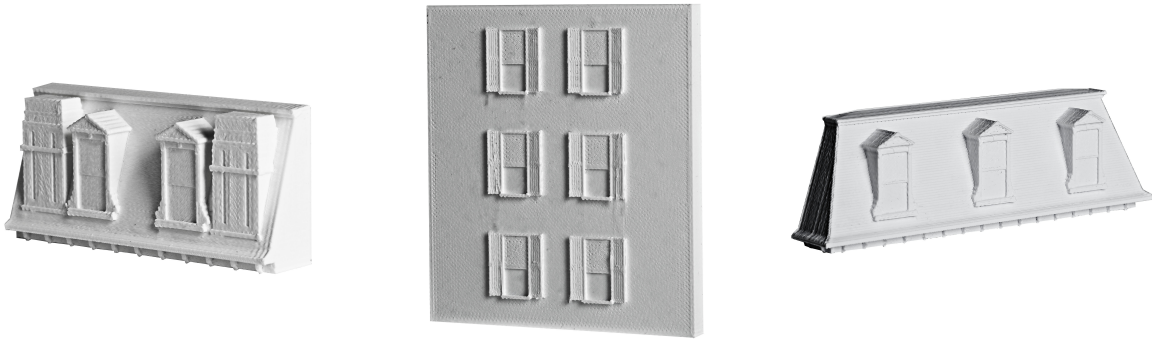
(a) Printed slice of the side of a roof



(b) Printed slice of the side of a house



(c) Printed slice of the front of a roof



(d) Printed slice of the back of a house



(e) Printed slice of stairs



(f) Printed slice of the top of a roof

Figure 5.3: Photographs of printed slices from the Enoch Pratt House model

(a) 3D print of the model of the Hamilton-Turner Inn (Fig 5.1a)

(b) 3D print of the model of the Enoch Pratt House (Fig 5.2a)

Figure 5.4: Photographs of the finished 3D prints of the houses
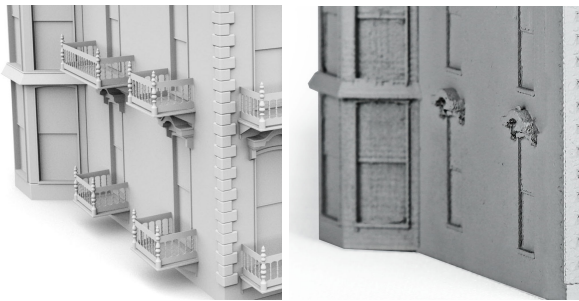


(a) Comparison of missing details (balconies) in the 3D vs printed model of the Hamilton-Turner Inn

(b) Comparison of missing details (balconies and porch posts/railings) in the 3D vs printed model of the Enoch Pratt House

Figure 5.5: Comparison of missing details between the 3D models and 3D prints

# 6.   CONCLUSION AND FUTURE WORK

## 6.1   Conclusion

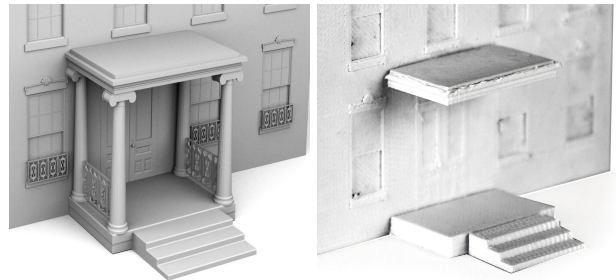This paper presents a procedural method for the creation of 3D models of a wide variety of American Second Empire houses and a means of 3D printing those models to create a visual aid. As this method can represent not only currently standing houses but houses that no longer exist, it is an useful asset in the cultural preservation of this beautiful style of architecture.

## 6.2   Future Work

While our method covered the majority of types of Second Empire houses, this work could be expanded upon to include the 'asymmetrical' building type. Additionally, more models (such as windows, doors, etc) could be made and incorporated into the tool for an even wider variety of house designs.

Inside of Houdini, the structure of the tool could be redone to incorporate more VEX code and custom nodes. As VEX SOPs typically run faster than point SOPs, this could make the tool run more efficiently [29].

Our created digital asset could also be incorporated into other softwares and game engines, such as Maya, Unity, or Unreal. The parameters of the tool would then be able to be manipulated within these programs, allowing for easier use of the house models in animation or game environments. Additionally, a procedural UV system inside Houdini could be created and applied to our models in order to apply textures to them in these softwares.

In regards to 3D printing, the houses could be printed at a larger scale in order to include the details such as the balconies and cresting, as well as the pins and cavities, although this would not be ideal because of the increased price of printing. Another alternative would be to caricature the more delicate aspects of the buildings and make them larger and less in number, potentially making them printable  [24, 10]. Additionally, the house models could be sliced apart more in order to further drive down the cost of printing. The resulting prints could also be painted in a

realistic manner to more resemble their real-life counterparts.

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