When Hatch-Marks Miss the Mark

Incorporating Finishes into BIM

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Abstract

When Hatch-Marks Miss the Mark: Incorporating Finishes into BIM

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This research studies how Finish Materials are depicted in architectural blue-prints and drawings. It examines how they are commonly represented via the hatch-mark and seeks to improve this representation. By first defining historical use and then analyzing the current uses of the hatch-mark in today's different softwares, the study identifies gaps in both industry standardization and basic functionality. Both a Literature Review and Technical Review were performed to find out how well the hatch-mark tools work. These reviews identified a "Benchmark Hatch-Mark" to aid in construction and communication for the finish trades. These criteria and model were then applied to a case study of a landscaped green roof of a wastewater pump station. Through a mixed-method approach, the benchmark criteria were tested in drawings, real-world installation, and interviews. The goal is to make 3D Finish Models more accurate and improve clash detection. This will in turn move BIM technology forward.

Key Words: Hatch-Marks, BIM, Clash Detection, Finish Trades, Parametric Modeling

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When Hatch-Marks Miss the Mark

The Finish Trades have yet to fully leverage computer drafting technologies into the construction process. This lack of technology use, like 3D modeling, leads to ongoing constructability challenges in the construction industry. For the past half-century, the industry has been infamously slow to adopt emerging technologies (McCoy, Yeganeh 2021). It is only recently that key trades like Mechanical, Electrical, and Plumbing (MEP) have embraced new Building Information Modeling (BIM) processes. These processes have helped the construction industry with new technology like modular builds, virtual constructability reviews, and 3D fabrication. They have also helped streamline communication and construction methods in the major trades. Often called “Federated”, 3D models have become a standard contractual deliverable on major construction jobs. These models have shown to aid in MEP coordination and construction.

However, the slow rate of BIM adoption and implementation for specialty contractors and Finish Trades has limited the efficiency of project communications (Huda, Hilal 2024). This research will first explore the fundamental communication tool used in finish and specialty trade drawings, the hatch-mark. The research then aims to create and test a set of criteria aiding in incorporating parametric finish design to BIM, thereby resolving some of the communication issues.

Parametric design in this research will focus on parametric modeling. Parametric modeling is a look at the relationships between architectural dimensions and various parameters, enabling the manipulation of forms through mathematical functions (Davis 2013). In the world of the Finish Trades, the project parameters can be viewed in the drawings and specifications. Communicating those parameters, however, remains a problem. Project contracts specify finished materials but there is an often-unacknowledged relationship between finishes and other trades such as structure in constructability reviews. One such example is between the major structural concrete pours and finish tile floor installations. In this example, the two trades are intimately linked and designing one has a parametric influence on designing the other. If tile thickness increases, for example, concrete slab thickness must decrease. Specifications like floor flatness, waterproofing, reinforcement, and mortar thickness all have a parametric impact on overall design (TCNA 2024) and the relationship between the substrate (e.g. the concrete floor) and the tile assembly. Early integration of BIM and 3D models by project stakeholders including the Finish Trades will improve project efficiency, communication, and success.

What does early integration look like? The stakeholders should provide a digital platform for specialized trades to communicate both detailed schematic and schedule needs. The success of a project can depend on this early invitation. In fact, it is these early stakeholders that are responsible for integrating the finish and specialty trades into BIM. For example, a tile floor in a bathroom could have a specification for heated elements that would require electric components to be installed prior to the tile. In this instance, the finish trade becomes an intrinsic part of the entire building system. Incorporating these details into an early 3D constructability phase avoids unnecessary and costly rework because of parametric design influences. The heating elements might specify a specific voltage of wiring to be installed or the controls might require its own junction-box. Electricians would install these before the drywall goes up and the finishers arrive on site. It’s possible for a mistake early on to remain in place until the end, when it would be more costly to remove the drywall and bring the electricians back to reroute their work. As such, an early technological invitation by the project managers to the BIM MEP dialogue becomes indispensable. In essence, BIM allows us to broaden the scope of clash detection from the main trades to all trades. It is time to take advantage of that technology.

Therefore, the research question at hand focuses on incorporating the Finish Trades into a 3D model that leverages coordination between structural, MEP, and Finish Trades.

How can we improve upon existing Finish Trades models and systems to increase communication and prevent field rework?

Like their larger trade counterparts a decade ago, many smaller specialty and Finish Trades have yet to fully incorporate new technologies into their building methods (Nunung 2023). There could be many reasons for this. Firstly, a lot of the smaller Finish Trades simply don’t have the budget nor staff to adopt new technologies. Software can be expensive and training takes time.

Next, finishes are numerous and difficult to quantify in the drawing. A single wall in a building could be covered in either paint, wall paper, tile, wood panels, PVC panels, and so on. Third, a lot of the aesthetic decisions for finishes can be left until the end of the design process, delaying a trade's ability to participate in the early BIM coordination and dialogue. The Finish Trades are often the last subcontractors working on a job site. Their work involves the "finishing touches" like paint, tile, landscaping, and carpeting that typically gets scheduled later in the project. This natural timeline of a project can have adverse effects on the Finish Trades, as they are more likely to encounter problems like diminished project float or shortened schedules to meet opening deadlines. Coordinating the constructability of those trades becomes an afterthought, something to verify and fix in the field.

Creating models that include finish information seems overwhelming for both current technology and the workforce. For example, figure one is from a Federated MEP NavisWorks 3D Model (Figure 1). We can see a constructability issue between piping in the ceiling and a glass panel in the room. What is missing is the floor and wall detailing. The graphics are simple, meant to highlight the major systems only. But perhaps a look at the finished flooring might help with problem solving. Depending on the thickness of the flooring, the panel could be moved up or down. With no visual cue to aid in troubleshooting, issues and solutions get overlooked.

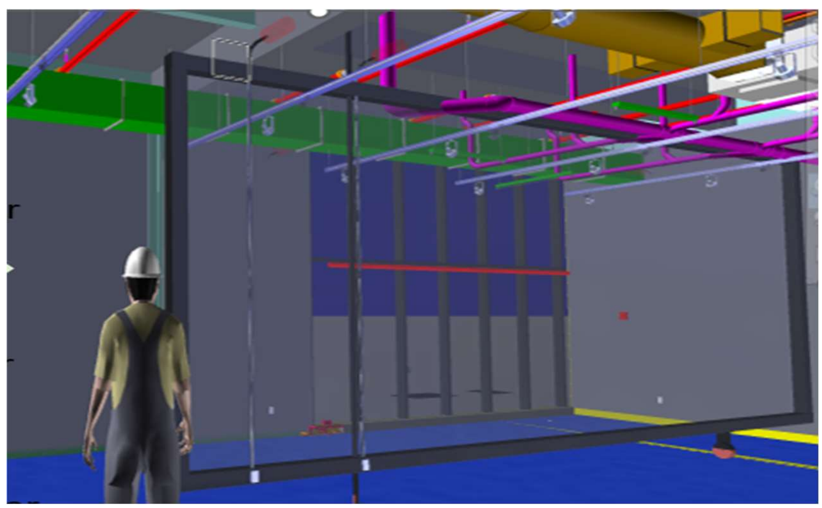

Figure 1: Clash Detection Walkthrough in BIM 3D Model

1. Background- Finishes and Parametric Modeling

What are "finishes" in the construction industry? It is a rather broad scope of work and includes both exterior and interior materials. Exterior finishes can be hardscaping material used for paving surfaces, such as walkways, or stone-clad walls on a building. They are usually made of materials like metal siding, brick, or stone and come in various shapes, sizes, and thicknesses.

Exterior finishes can also include landscaping, where installed turf, trees, and plants are considered “finish product”. Interior finishes have multiple material choices as well. They can include floor and wall coverings, finish carpentry like ceiling trim and casework, paints and water-proof coatings, flashing around elevator doors, anti-slip stair treads, and so on. Finishes are as numerous as there are materials on earth. A good way of envisioning the Finish Trades is by imagining oneself walking into a building. The immediate impact of that finished work is felt upon entering and can define a building’s role. Sleek and simple finishes shape a modern environment while detailed carvings and craftwork lend a more traditional aesthetic. Utilitarian finishes can define workspaces like commercial kitchens while other finishes can highlight paths of egress in case of emergencies.

This notion of finishes defining a building’s role is important, as they are more susceptible to remodels and updates throughout the building’s lifecycle. Fads and trends in interior design can be a catalyst for remodels, but finishes can also get updated to incorporate new technology and standards. It is the finishes that play a key part in the very utilization of the building. Therefore, this research study is defining finishes as materials that combine both **form** and **function** in a building. As technology used in the construction industry evolves, it is essential to translate the Finish Trades into designs with both form and function in mind.

This is where parametric modeling within the hatch-mark has failed BIM and the Finish Trades. Current software design standards only include the “form” for the finishes. BIM first emerged as a tool used to incorporate technology for construction over a decade ago (Levy 2011). Recall the earlier definition of parametric modeling. The idea of limitations in materials, means, and methods has been incorporated into BIM design. Autodesk defines parametric design as a “feature in AutoCAD that assigns constraints to objects, establishing the distance, location, and orientation of objects with respect to other objects” (AutoCAD 2024). This software allows drafters to assign geometric and dimensional constraints to objects in a drawing. As a 3D digital representation of both the physical and functional attributes of a structure, BIM can help clarify and revise the project design as well as helping with constructability reviews and structural coordination.

However, the very nature of finishes makes parametric and dynamic incorporation into software difficult. Material finishes are innumerable, with each requiring different specifications and methods for installation. But perhaps a parametric hatch model drawing from a large database could supply that type of information. The below outline lays out how I explore such a model and how it answers my research question of improving Finish Trades communication.

First, I explore the finishes through literature. I found the existing research highlights the need for better project coordination in the Finish Trades. These studies analyze the integration of Finish Trades with other trades. They also examine the technological tools used for design representation. This examination led me to evaluate current technologies. This evaluation revealed gaps in hatch-mark varieties, especially in integrating form and function. These gaps allowed me to define the criteria for an ideal hatch-mark model based on literature and technology assessments. Next, I incorporate the newly defined parametric benchmark hatch-mark model into a Case Study. This study focuses on a pump station green roof as a finish product, analyzing the construction documents in light of the newfound criteria. The findings underscore the importance of advancing technology in the finish materials. They offer implications for future research and practice in construction project coordination. Recommendations focus on further development of hatch-mark technology and user interfaces.

2. Literature Review

The literature reviewed in this thesis looks specifically to those researchers interested in streamlining finish material and finish design in the BIM landscape. I reviewed fifteen different models for incorporating finishes into BIM. Broadly, the research in finish models within BIM falls into two categories: enhancing existing finish models through parametric design and innovating new approaches for future construction applications.

First, I focused on the researchers performing parametric design within CAD to gain an understanding of existing hatch models. These studies were centered around the term **hatch-mark** and looked to achieve a clear and legible design (form). Modelers under this category focused on surface geometry-based hatching techniques (Singh & Schaefer 2011) . Their techniques help to create legible hatch patterns that reflect real-world materiality. For example, some researchers optimized vector fields in AutoCAD to create smoothed curvature paths for the hatched lines (Hertzmann & Zorin 2000). Their vector fields were coded with parametric hatching features over pixelated raster data, facilitating smoother designs. Other researchers worked to ensure line spacing and density were controlled across model spaces (Zander et al. 2004). Designing this type of parametric control within the hatch-mark helped to avoid dark areas once it was plotted.

However, I discovered that these hatch models still focused on the visual output of the hatch-mark as a static 2D layer (form). For example, the figure below illustrates the parametric programmed hatch-mark by Wu, Zhang, Lup et al. (Figure 2). Their program designed an efficient tile layout using AI for custom cuts. However, the parametric design incorporated within this program is still on an *x* and *y* axis. We know how wide to make the cuts at the threshold of the bathroom, but not how deep the mortar needs to be to flow into the rest of the apartment. Once the parametric hatch command was set within the software, the tab was exited and the hatch-mark existed as an isometric object on the page. This could be because most of the literature exploring these hatch capabilities was from twenty years ago. AutoCAD was still rather new and drafters were excited about the possibilities. A lot has happened in technology since then. For example, in 2013 AutoCAD released an "Associative" command that automatically updates the size and width of the lines within the hatch if the boundary changes (AutoDesk 2024). This update addresses much of the previous literature's ideas on parametric hatching. These are "smart" dimensions that automatically adjust to changes. If you change the size or shape of the object they're measuring, they update themselves to stay accurate. The below screenshot shows an image I took while creating a hatch boundary, depicting other features that

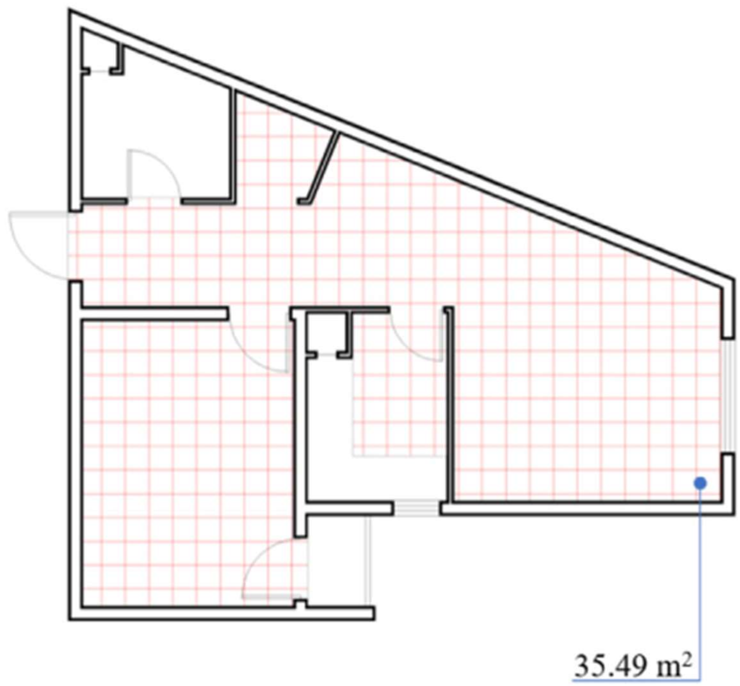

Figure 2: Automated Layout Design Approach of Floor Tiles

have since been added to the software. This includes an "Annotative" scale that adjusts the hatch scale to the zoomed in image (Figure 3).

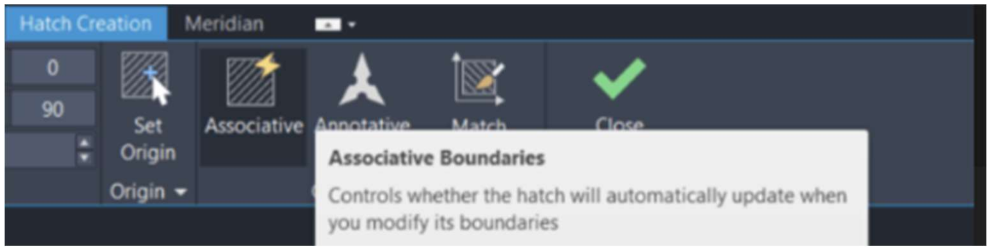

Figure 3: Screenshot of Associative Boundaries in Hatch Creation

In short, *associative* dimensions save you time by updating automatically, while *non-associative* dimensions may still require some manual updates. The idea of a parametric design is starting to exist within the software, but previous background literature shows that the link between form and function does not yet exist. I had to therefore dig deeper into the literature to find examples of parametric designs of a hatch-mark as an object.

The example of "associative" hatching highlights the rapid growth of 3D hatch-mark modeling and justifies limiting the study of the next round of hatch models to recent articles (the oldest being eight years). By subsequently narrowing criterion to the year the literature was published, I was able to map the evolution of newer hatch-models in the industry to older. Because technology tends to evolve quickly, in this next step I prioritized literature published after the year 2020. This is where the second key theme of the literature emerged- that of creating a hatch-mark that can parametrically function in future construction projects. After analyzing the literature that sought to improve existing finish models, two interesting sub-criteria emerged using hatch-marks for construction planning and using them for building.

These models focused on newer technologies in the construction industry, with 3D printing (Murphy 2020 and Kalkatechi 2017) and Artificial Intelligence (AI) finish materials layout (Wu et al 2022, Wu et al 2023, Deng 2020, and Daemok 2022) emerging as the most popular examples. Updating hatch-marks to work with AI and 3D printing goes beyond simple lines or textures on a design. For example, Wu et al in figure 2 utilized AI to analyze and predict the most efficient way to lay out tile patterns on a surface, considering factors like material usage and grout joints. This means that the hatch-mark isn't just a visual cue; the researchers tried to parametrically optimize it for real-world settings.

In 3D printing, hatch-marks took on an even more direct functional role by shaping how material is printed to reinforce strength or flexibility in a structure. For instance, a printed hatch-mark can act as an internal skeleton within a component, ensuring it's lightweight yet strong. By treating the hatch-mark as both form (its appearance) and function (its practical role in construction), these researchers transformed it from a simple design element into a crucial part of building and manufacturing processes.

The biggest room for improvement found in the Literature Review was the concept of the hatch-mark as 2D. Some of the ideas within improving hatch-marks via AI cost-estimating methods (Wen 2023, Al Rahhal 2022, Dae-mok 2022, Martina 2023, and Al-Rahhal 2022). This makes sense, as my earlier observations on the multitude of finishes reveals a need to organize and automate the information. Recall figure 2 that depicted a parametric hatch-mark for a tile layout. The 2D lines do not truly account for the different finish materials. The mass quantity and types of finishes need a user-friendly rolodex in which one can "click" on a hatch-mark and access material specifications, scheduling, and cost. Interestingly, a common theme in creating AI software programs to both identify and improve upon finish trade cost-estimating methods has emerged for the finishes. For example, researchers Al-Orabi and Al-Gahtani programmed a finish cost-estimating tool for Revit by manipulating the hatch-marks via "nodes" (Al-Orabi 2022). They were able to analyze the cost versus quality of various finish materials like ceramic, porcelain, and marble in a 3D BIM platform before they were specified for installation.

The second process sought to improve upon existing finish design workflows and frameworks (Ha 2022, Teo 2022, Al Rahhal 2022, Wu 2021, and Huda 2023). These workflows and design frameworks for finishes incorporated different methods but tended to lean on the idea of AI for finishes. For example, researchers Dae-Mok, Young-Su, and Bon-Sang created a rule-based parametric modeling system that automates the design of interior finishes (2022). Wu et al. created a parametric design workflow to optimize tile design (2022). Martina, Anggraemi, and Hasan created a Level of Development (LoD) comparison tool for BIM finishes (2023). Current finish hatch models are largely focused on technical advancements, with less attention to installation information that would directly impact practical outcomes like communication and field rework reduction.

These latest ideas were grounded more in the theory and less in the technical aspects of the software witnessed at the beginning. Overall, these explorations into the future capabilities of BIM technology and for Finish Trades in particular barely scratched the surface, mostly focusing on hatch-mark as function. When I refer to the hatch-mark as both form and function, I mean it is more than just a visual pattern, it also has practical applications in construction and manufacturing. Most of the models described above relied on the reformatting of the hatch as a 2D linear notion. In other words, the literature reviewed explored the notion of creating easier software/applications for only the finished visuals of the hatch, often ignoring installation methods. Despite the advancements in technology, hatch-marks were still seen as primarily 2D visual elements. These models often neglected the crucial link between design intent and installation requirements. A tile floor can have a completely different installation process in either a wet area or a dry area. These two environments could have the same material but different methods of solving problems like ADA compliance, slope distance for shower drainage, flooring transitions, floor flatness for tile lippage, mortar thickness, and others. These standards create parameters, one in which a hatch-mark can be defined. The hatched array could be constricted within the distances allowed to accommodate afore-mentioned standards. In essence, hatch-marks act as the communication chain between the designer and installer. To completely engage with the construction process, the models and uses of the hatch-mark still need to integrate 2D and 3D definitions. To this end, a hatch model should incorporate **parametric** design for **function** along with visual attractiveness for **form** and clarity. The goal of this review was to investigate the present-day use of the hatch-mark and seek improvements for future technology.

4. Methods

As explored earlier, hatch-marks are symbols that contain both form and function. When defined as function, hatch-marks have a tangible physicality in the real world. This requires a more software-oriented approach to analyze the standardized industry data. Conversely, hatch-marks also represent form, a difficult to define aesthetic that can get translated through raster images into design packages. The form of the hatch-mark requires a qualitative approach to define. These two definitions of the hatch-mark therefore require mixed-method analysis.

I created a two-pronged approach to study hatch-marks, theory building and then theory testing. Theory building focused on software while theory testing on the field. This approach enabled me to first gather the data and then study the function of the hatch-mark. Results were then compared to a qualitative case study, studying the form of the hatch-mark. I then based my analysis on matching patterns across these different data gathering methods (Yin 2018), looking to either confirm or reject my theories on 3D hatch-marks. Below Figure 4 helps to illustrate my approach and data analyzing methods:

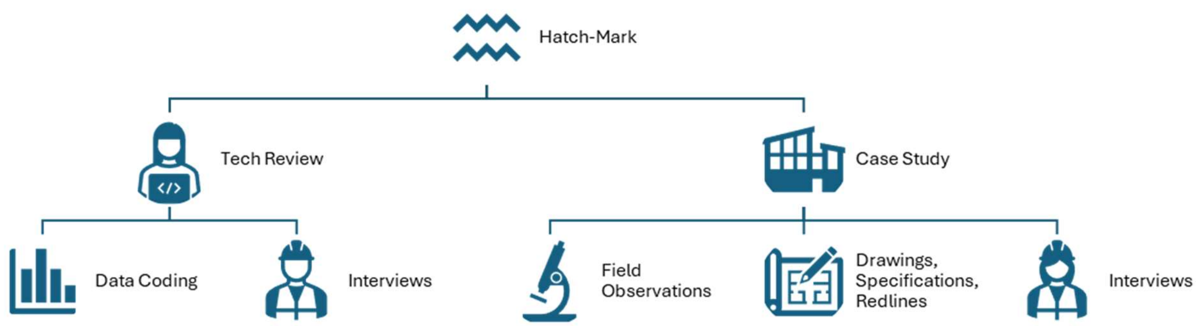

Figure 4: Hatch-Mark Chart Depicting Research Method Breakdown

4A. Technical Review

This Technical Review supplied me with both a hatch-mark criteria and a compelling model of a 3D example to use for a Case Study. The reviews focused on different software under the AutoCAD family (AutoDesk:AutoCAD, Revit and Navisworks), as well as other software like Bentley Systems, Rhinoceros (includes Grasshopper), Adobe's Trimble (including SketchUp and Tekla) as well as Bluebeam Revu 3D. The software chosen for the review was based on the 2023 market share in the 3D modeling Industry (Market&Market 2024). This report analyzed the compound annual growth rate (CAGR) from 2018 to 2023 of worldwide 3D modeling companies. The report divides the results by region, and I focused on the US market and its top five CAGR rated software. This is because the US market has the highest share of growth and income of 3D technology worldwide. Moreover, the report also revealed the market size for 3D software in architecture, engineering, and construction is larger in the US than other markets like entertainment and government defense.

I compared the software and their hatch-mark capabilities via two different approaches. First, I created a spreadsheet focusing on three different criteria:

1. Variety and customization of hatch-mark creation.
2. Conversion to 3D and BIM software capabilities, existence of third party "add-ons".
3. Performed a "command-count" with each software to count exactly how many physical steps it takes to create an angled tile pattern.

This comparison analyzed software's simplicity of hatch editing, 3D extrusion capabilities, pattern options, total hatch systems, and any notable add-ons or features.

After a brief overview of available CAGR software, I decided to narrow my review even further. This review focused on the current basic functionality of the hatch-mark across four different software packages: Revit, NavisWorks, AutoCAD, and SketchUp. This narrowed scope was to focus on BIM and the 3D capabilities of the corresponding hatch-mark.

Most of the raw technical data on hatch-marks was culled from the software's manuals. The manuals provided manufacturer instructions on the creation and functionality of its hatch-mark. I summarized the key instructions and capabilities of each software and coded them for common themes. For extra discussion and in seeking answers to my own hatch-mark struggles while performing the research, I also gathered information from the corresponding software's online help forums. These forums offered a platform for end-users looking for help with digitized and BIM modeling hatch functions. End-users struggling with various hatch-functions were answered either by a software representative or other more knowledgeable end-users. This type of data source provided a great wealth of information in looking at both how the end-users of the software's hatch-mark interacted with the technology and any challenges they encountered. The information was included in the coded spreadsheet to fill in any gaps and expand upon hatch-mark capabilities.

Using the three criteria, the different hatch capabilities were compared by using a simple System Usability Scale (Appendix A). SUS rates software usability on a scale 1 "strongly disagree" to 5 "strongly agree". Using this point scale, each software was first rated and then compared. Some of the numerical comparisons were as simple as counting the number of steps each software took to complete a hatch edit. Other criteria were first coded for themes and then compared via the SUS scale.

The results of this technical review provided me with a model of an all-encompassing hatch-mark "system" to then use in a case study.

4B. Case Study

In order to answer the research question of **how** to incorporate a well-designed hatch-mark into the building workflow process, I wanted to examine an example of a hatch-mark in a real-life project. This Case Study triangulated data from multiple sources. The hard data was gathered via 3D Lidar software and analyzed via point clouds in 3D. Project drawings and documents were analyzed via comparison. Lastly, stakeholder interviews were coded for themes.

For this case study, I chose to analyze a new green roof installation at a county wastewater pump station. A "green roof" is also known as a living roof or eco-roof and is a sustainable building installation that functionally integrates vegetation onto the roofs of buildings (WGIN 2021). Some of the most important features in a green roof is the water-proofing system, an important function in preventing the roof from leaking. However, recall the common problem of waterproofing being depicted in drawings as mere lines under arbitrary hatches. By examining the construction drawings and focusing on hatch-mark translations in the field, this case study examined how they helped or hindered the installation process.

The green roof installation provided an excellent opportunity to study the role of hatch-marks in construction drawings. This study focused on how hatch-marks were used in conveying material selections and alignment, depicting drainage systems, and showing the layers of soil and vegetation required for the roof's functionality. As I analyzed the drawings for this green roof installation, I wanted to explore how the use of hatch-marks improved/hindered communication between architects, engineers, and contractors. I focused on the hatch-mark's role in conveying essential information during the design, execution, and operation/maintenance stages. I did this by assessing the accuracy of hatch patterns and its corresponding installed system via a triangulated data collection method.

I gathered data using multiple sources of information via triangulation. The three sources of information included computerized data gathered from field observations, archived project drawings, and professional interviews of those involved in the project. After coding and analyzing the data, I then applied my hatch model gained from the tech review and compared it to the project. This helped me dig deeper into the process of designing with hatch-marks, and enabled me to present recommendations for a 3D incorporated hatch system.

Method 1- Lidar Field Observations

The pump station itself is difficult to access, requiring coordination with offsite operations and security. I was allowed to tour the site just once, so therefore had to take advantage of the opportunity. While on the Green Roof, I used a BLK360 LiDAR camera to record my field observations. LiDAR is a mapping technology that uses laser light to measure distances (NOAA 2024). It creates detailed 3D maps of various surfaces by stitching together a "point cloud" of laser points. The red dots depicted in the scan represent various scanning set-up points of the camera. I set up eight total scan spots on the green roof to capture all directions and to ensure complete scanning around HVAC obstructions located on the roof. I then downloaded the scans into a point cloud and created a 360° map of the green roof (see Figure 5). I then used this map to compare archival drawings, specifications, schedules, RFIs, and redline drawings outlined in method two.

Figure 5: Screenshot of LIDAR Scan of Green Roof

Method 2- Archival Drawings, Docs, Specs, and RFIs

This analysis began by looking at pre-project archived drawings of the building. These drawings provided a baseline for the current project and revealed the extent of the renovation. These historical drawings acted as my "control" as I compared the newer drawings. I chose an archived drawing from the late 1990s drafted via computer. Firstly, I wanted a drawing that was drafted in AutoCAD rather than an older one drawn manually. This was to narrow the scope of the comparison to within a computerized hatch-mark.

Once the historical plans had been studied, a comparison with the modern drawings became the next step. In this phase, I focused on identifying how the newer hatch-mark tools had improved communication and material precision. I looked for differences in the way materials, slopes, and drainage systems were represented.

Once the visual comparisons were noted, I moved on to the redline drawings and the Requests for Information (RFIs). These documents presented me with a "back-stage" look at the design and construction of the green roof. I noted any questions regarding the installation on the green roof and flagged them for further research in my third method, interviews.

In the next phase of the drawing analysis, I cross-referenced the drawings with real-world conditions. This was where the LiDAR scans became important, as they provided three-dimensional models of the "As-Built" environment. Comparing the intended design to the actual construction allowed me to detect discrepancies between what was planned and what was built. In this process, I investigated whether errors or misalignments in the drawings had led to deviations during construction. Had misaligned hatch-marks or unclear notations caused material to be cut or placed incorrectly? These questions guided the second aspect of the analysis.

Attention was also paid to the practicalities of installation. For example, a worker using these drawings in the field might have encountered challenges if the design had not accounted for the realities of construction, such as roof slopes or drainage requirements. It was my job to consider how much burden had been placed on the workers to interpret vague or ambiguous details on the plans. I evaluated whether the drawings had provided enough information for efficient installation or if they had left too much open to interpretation. I based this analysis on my own field experience as an installer. This information was provided by the redline drawings and RFIs.

Finally, the entire analysis looped back to my core question: did the hatch-marks lead to successful project outcomes, or had it hindered the process? By comparing the details of the project drawings, I identified where errors had originated and how they had impacted the final construction. This allowed me to make recommendations for improving future hatch-mark conventions and modeling technology.

Method 3- Interviews

With the drawing comparison complete, I wanted to search deeper into some of the problems encountered on the project. I conducted interviews with key players in the green roof project: an engineer, a project manager, and a drafter. The aim was two-fold. First, I wanted to listen to their experiences with BIM and any processes they might have for integrating hatch-marks into designs. The methodology centers on extracting real-world insights from these professionals, whose expertise spans both technical software usage and hands-on construction. Second, I wanted to ask specific questions about the green roof. This was to clarify any notes I had from studying the drawings and to ask for first-hand accounts on the problems revealed in the RFIs.

The interviews started by framing the questions in an open-ended manner. This allowed the interviewees to share their experiences freely and in-depth. The first set of questions, for instance, focused on the interviewees' backgrounds and whether their approaches were more computer-based or field-based. This helped me establish a foundation for understanding their perspectives on construction and modeling.

The next step in the methodology was to analyze the responses. This is where qualitative coding comes into play. The interview responses were transcribed and then coded to identify recurring themes, such as challenges faced during the modeling process or preferences for certain software tools. I searched for patterns in their answers, such as how frequently they mentioned issues with constructability or software limitations. Each piece of feedback added to the overall picture of how the current hatch-mark modeling techniques meet, or fail to meet, the demands of real-world construction.

Employing thematic coding and synthesis of data helped reveal the underlying challenges in hatch-marks. It also helped to understand how the current models function in the real world and how they can be improved for future projects.

5. Findings

The tech analysis combined with the case study confirmed my 3D theories of the hatch-mark. Incorporating a parametric 3D hatch-mark for the Finish Trades will increase project communication and success.

Hatch-marks act as crucial communication tools between designers and installers. They carry implications for installation methods based on material, environmental considerations, and building codes. For instance, the same tile material may need different installation methods for a wet versus a dry area, and hatch marks can preemptively address issues such as ADA compliance, drainage slope, and flooring transitions. Therefore, for hatch-marks to be effective in practical applications, models should evolve to encompass both 2D and 3D definitions that integrate parametric design with technical clarity.

5A. Tech Review

First, I wanted to discover where the breakdown in communication of 2D to 3D occurred. A historical analysis was first conducted on the hatch-mark. Hatch-marks traditionally have two uses: symbolic and geometric. To explore these different uses, one must first travel through time and follow the hatch-mark's journey through history.

Figure 6 Egyptian Drawing of a Garden. The Met

Hatch-marks in architectural drawings have been used to aid in design communication for centuries. One of these first examples depicting a set of plans for a structure can be found in

Egypt circa 1550 BCE (Figure 6). Interestingly, this small shrine and garden plan features W-shaped hatching to depict water and other symbols showing landscape features and vegetation. These hatch-marks served as visual cues, aiding the observer in understanding the intended spatial relationships and features within the design. This example from history helps us define the first role of the hatch-mark- that of the symbol (Dodds 2013). Hatch-marks are integral symbols in architectural drawings, conveying lots of information with simple designs.

The Roman era builders literally cemented the hatch-mark notation into their architectural drawings (MacDonald 1982) by recreating them in stone mosaic form. For example, a mosaic dating from the 2nd or 3rd century BCE depicts elaborate bath plans with apses and segmental walls (Figure 7). The mosaic consists of three fragments showing different parts of bath buildings. The various rooms feature dimensions depicted in Roman Numerals that a master builder might use. We can also see that the details of the interior are symbolized via different colors and hatch-marks. The location of the basins and pools are marked by green tesserae, for example, outlining the extent of the wet areas. Compare this color to the darker blue tesserae marking a water channel in an outer corridor, and we get a sense of an ancient 2D drawing coming to life through colored stones. These stones are, in a sense, 3D hatch-mark blocks.

Figure 7 Mosaic of a Roman Bath

This added incorporation of different colors into architectural drawings allows for a descriptive representation of spaces within a building. Moreover, the use of colors enhances the aesthetic appeal of architectural drawings, making them more engaging and captivating. This mosaic, for example, was installed by a craftsman as a piece of art to be enjoyed. The intricate mosaic patterns and vibrant colors transform what could have been a simple depiction of architectural plans into an elaborate and visually striking artwork. Here is where the idea of the hatch-mark as visually symbolic truly begins to form.

Using symbolic hatch-marks for plan readability was formalized in the 17th century's Renaissance era (Overstreet 2020). This period is famous for celebrating artistry, and newly planned buildings and blueprints were painted in gorgeous oil landscapes. At this time, the first so-called “Hatch-System” was created. The importance of this system was to standardize the reproduction of heraldry colors and materials in coats of arms. Hatch-marks were used to depict specific colors and materials that could then be read by trade professionals and later reproduced. The below figure shows one of these examples; where *A* represented brown; *B* was blood-red; *C* was an earth-color; *D* was the metal iron; and *E* water; *F* was flesh-color; *G* gray; *H* was orange; and lastly *I* depicted the color of nature (Figure 8). The use of the hatch-mark as an official

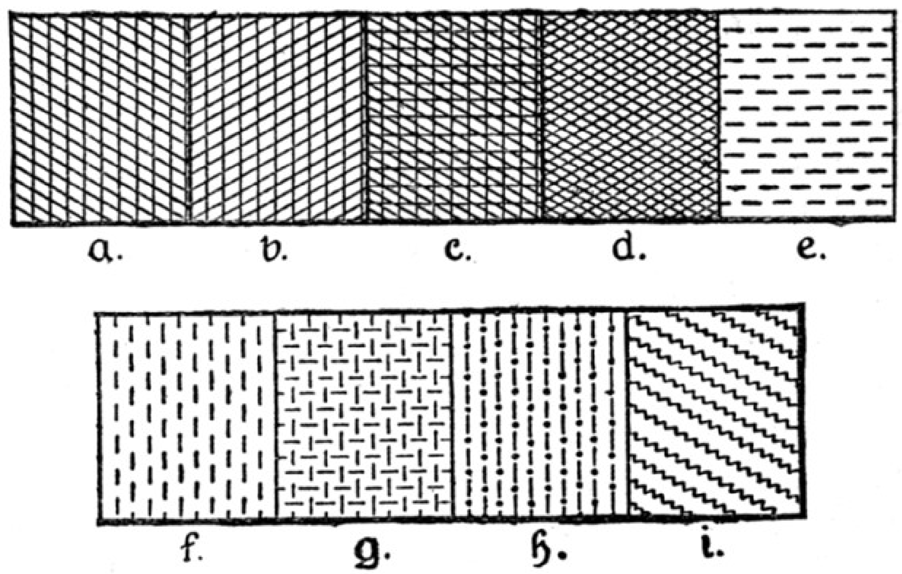

Figure 8 Hatch-marks used in Heraldry

symbol can still be seen in use today. The heraldic hatch-mark symbol used for the metal gold, for example, is the same hatch-mark used in architectural drawings today as it was in 1600 (AIA 2017).

In the 1850s, blueprints were invented and used for quickly replicating architectural drawings (Overstreet 2020). Now easily copied, hatch-marks were no longer meticulously hand drawn over and over. A few decades later in the 1920s, the first Architectural Graphic Standards book was published and officially categorized the hatch-marks (AIA 2017). This categorization regulated the line widths, spacing, and shapes of commonly used hatch-marks. It also established a difference between hatch-marks for common symbols and illustrative graphic shading, as well as hatch-marks used for different materials. It is this second definition that is of interest to the builder, as it is the materialized hatch-mark that represents an installation on the job site.

Historically, the finishes on a building were constructed from local and reliable building materials (Weber 2023). The first designs were launched out of the material's form **and** function. Famous German architect Gottfried Semper's *Theory of Cladding* suggests that the visual elements of a building, its decorative outer layer, are not always tied to its underlying function or materials. Semper emphasized that the cladding, or decorative skin, was primary in architectural design, while the actual wall was secondary. In his discussion on this theory Ralf Weber translates for us, "Cladding of the walls was the original...and essential [aspect of design]; the wall itself was secondary" (Weber 2023 pg. 197).

Historically, marble quarried locally became literal building blocks of a foundation, while also forming beautiful mosaic floors.
Today, instead, the finished material is rarely used as an engineer's design foundation. The Theory of Cladding also serves as a perfect example of how the construction industry started to evolve from a master-builder that drew the 2D designs while knowing the 3D impacts, to a group of architects and engineers drawing for separately contracted builders. Figure 9 illustrates this shift beautifully, depicting draftsmen from the late 1950s. In this case, the slide ruler is the hatching tool and there is an obvious physical separation between design and craft (Figure 9). The hatch-mark started to be defined wholly as a design feature, forgetting the inherent installation behind the symbol.

Figure 9 Aircraft Engineers- 1957

Construction designs need to communicate tangible and measured ideas, not just intent and symbols. The other definition of hatch-marks as geometric then comes into consideration. When used in graphs, hatch-marks are used to mark points on an axis and along lines. When used in geometry, hatch-marks are used to denote equal-measures of angles, line segments, or other objects (Caron 2011). These ancient geometric principles are important because in 1982, AutoCAD used these basic mathematical definitions to digitize the hatch-mark with its technological drafting software (AutoCAD 1982). Under this new age of architectural drawing, the first parametric model of the hatch-mark comes into play. For example, AutoCAD defines the hatch-mark as a file pattern in a simple x/y graphed format (AutoCAD 2023). These hatch-marks were defined geographically on an axis as the angle, x-origin, y-origin, etc. In this role, the hatch-mark as form becomes mathematically represented. The below figure 10 depicts an early AutoCAD example of this axis-based hatching system. Different materials are depicted either with more points or less points on the axis.

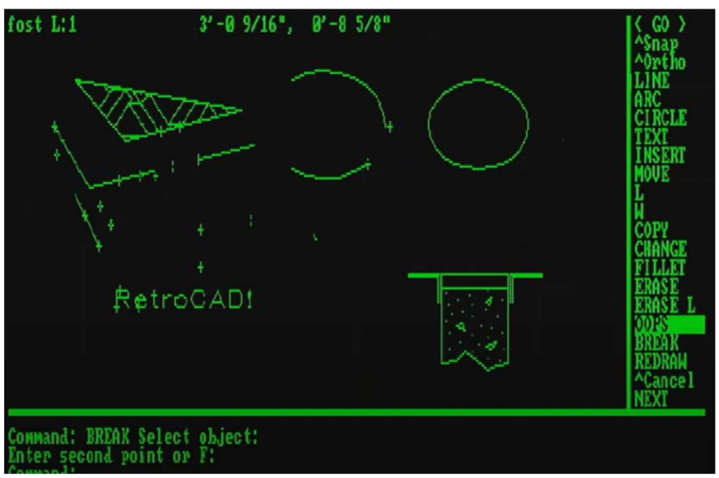

Figure 10 AutoCAD 1984 Hatch-Marks

Although the previously carefully hand-drawn symbols and lines were now in digital form, the underlying concepts of the hatch-mark were still in the traditional 2D format. Most current technology arrays hatch-marks with a simple click of a button and have no real 3D representation of the installed object. The hatch in this case is still a symbol, it is merely lines on a virtual wall with no true corresponding 3D modeling or installation notes.

In the early 2000s, the arrival of 3D construction management software like Revit and NavisWorks signaled a shift towards BIM. The idea behind BIM technology comes from object oriented parametric modeling techniques (Levy 2011). Solid shapes drafted within the 3D plan can interact with each other. With BIM, a designer was finally able to incorporate all the building's components into a single model. That model could then be utilized to produce floor plans, sections, and elevations.

The geometric principles I explored in the origin of AutoCAD still serve as fundamental design principles in 3D modeling (Levy 2011). The problem, however, still lies within this technical translation of the hatch-mark. CAD is based on the drafted representation of an imperfect hatch-mark (form, not function). In turn, various "BIM tools have inherited its computational geometric representation from CAD" (Abdirad & Dossick 2021 pg. 24). This inheritance maintains the status-quo of hatch-mark as symbolic and graphic (form), only hinting at the geometric and therefore parametric capabilities (function).

The hatch-mark has evolved from ancient symbolic 2D representation to 20th century drafting standards, and then morphed into today's 3D depictions. The historical analysis sheds light on the end user of the hatch-mark and how that has changed, along with changes in construction methods and technologies.

Method 1- Software Analysis

Next, I studied the current functionality of a hatch-mark across technological spectrums. This led to an exploration of different software and their proficiency in hatch-mark design. This is where I summarized the key instructions and capabilities of each software and coded them for common themes. This "coding" involved identifying recurring functionalities and features. It also looked at similar workflows or efficiencies related to hatch-mark design. In analyzing the raw data, the below word cloud helped me to visualize these recurring ideas appearing across the different software instructions for hatch creation (Figure 11).

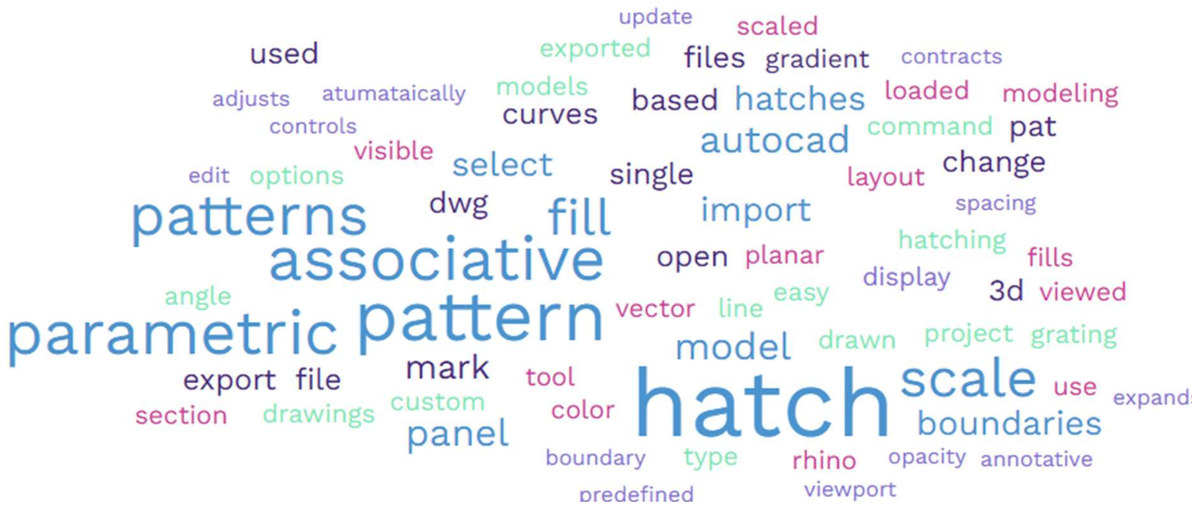

Figure 11 Word Cloud of Hatch-Mark Tech Commands

Firstly, I noted with interest the term “AutoCAD” repeating across almost all the different programs, not just those associated with the Autodesk daily (Revit, Navisworks). Almost every software analyzed had an ability to load or convert hatch-marks in AutoCAD. This let me know that the program is very much a cornerstone of the drafting industry, and any model idea I created for the future would have to be compatible with AutoCAD.

Next, I noticed repeating terms, like "associative," "parametric," and "scale" among the software hatch instructions. This suggested a focus on the form and flexibility of hatch-mark designs across different platforms. For example, I discovered many softwares distinguished between a “hatch boundary" and a “closed boundary". Hatch boundaries allow you to create associative hatching (stretchable) while drafting. These stretchable hatch-marks worked very similarly across software, incorporating “pick points” within the drawing to move the hatched lines. This allows the drafter to interact with the form of the hatch, updating various scales of line work. Essentially, most software incorporates parametric versions of the hatch-mark as “form”.

Conversely, there were also differences in the software hatch-mark creations. For example, looking at the result of a drawing revealed different hatch-mark outputs. The line densities of a hatch-mark plotted on a page varied across software. One can create darker or lighter hatch-marks depending on scale, layer color, and line thickness. There were a multitude of ways to reach these drafting techniques, both within individual software and across different companies. Recall that in AutoCAD, for example, one must first draw an "associative boundary" before editing the angle, scale, and spacing in a hatch-marked pattern (AutoCAD 2024). In contrast, Revit has a built-in "Fill Pattern" command that lets one customize the line angles and thickness (Autodesk Revit 2024). These differences showed me that there was still a dearth of defining the hatch-mark as "function".

Next, I created a mock project to assess the different workflows. By assessing the "command-count", I was able to quantify design efficiency for hatch-marks. The less mouse-clicks a hatch-mark took to create, the more efficient it was. I first established a simple hatch-mark to create in each soft-ware: a tile floor with lines spaced ¼" apart and with similar line widths for plotting. Below graph illustrates the physical clicking data gathered for each software (Figure 12):

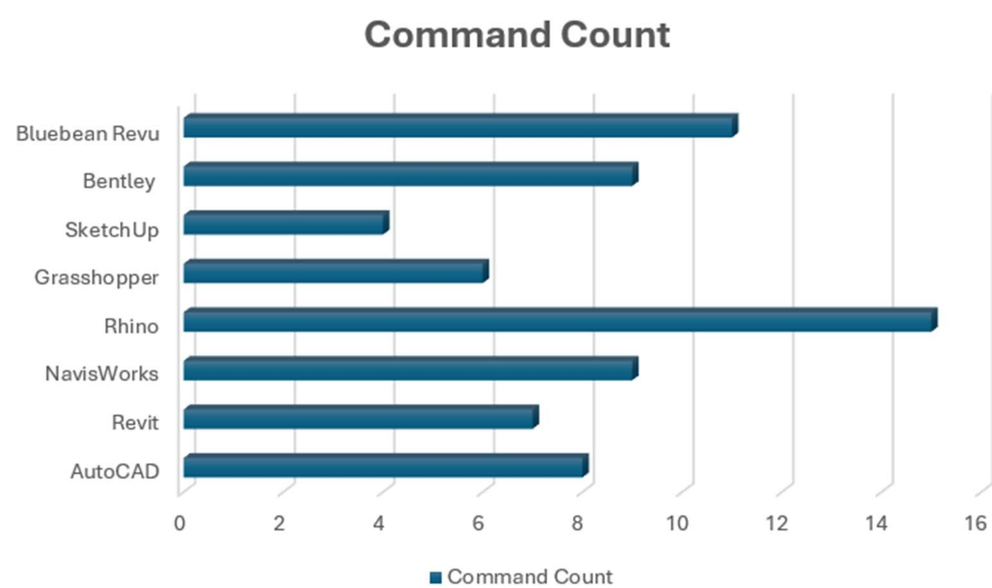

Figure 12 Bar Graph of Hatch Command Count

There were some obvious winners among the software. Based on the command counts, Rhino had the highest clicks with 15. This might be because of the software's requirement of closed plane curves for hatch-marks, making the scaling of the lines difficult to change. This might also explain the advent of Grasshopper to aid in the creation of hatch-marks. AutoCAD and Bentley's MicroStation had similar command usage at 8 and 9 respectively, suggesting the associative hatching in their applications are comparable in efficiency. Finally, SketchUp demonstrated the lowest command counts at 4, which may reflect its more targeted use of drawings in 3D. For example, elongating the width of a line takes more physical steps in AutoCAD software than in SketchUp. In this analysis, SketchUp is the most efficient hatch-mark creator.

At this point, there is a necessity for a note of caution. I am fairly new at interacting with some of the software and I followed the written commands via the manuals. This type of counting, however, does ignore "short-cuts" and add-on programs that come with experience. With experience comes efficiency and less overall total clicks. The hatch command count, therefore, portrays a basic understanding of the command for each software. Because of this, the count can be seen as a qualitative analysis based on novice experience.

Finally, I compiled empirical comparisons between the different software abilities. As I personally interacted with the software, I compiled a System Usability Scale (SUS) documenting my experiences. This consisted of me ranking my agreement with ideas like "I thought the system was easy to use" or "I found the system unnecessarily complex" on a scale of 1 to 5 (See Appendix A). This phase was where I was able to narrow the field of various software and pick the ones that had the most potential for translating a hatch-mark into form and function (Revit, NavisWorks, AutoCAD, and SketchUp).

Now that the review was focused on four main hatch-mark friendly software, I created another SUS to further analyze the end user experience with the hatch-mark. This data was culled from help forums posted to different technical sites. I then assigned the same SUS 1-5 scale based on the general amounts and types of grievances. Revit, for example, was purpose built for BIM and didn't have as many 3D issues posted in the forums. Conversely, AutoCAD is a stand-alone software requiring add-ons for 3D hatch-mark editing options. In this instance, Revit scored higher in a tech comparison than AutoCAD. On the other hand, I found hundreds more pages asking for help in the hatch conversion for AutoCAD to NavisWorks. This does not necessarily imply that the NavisWorks hatch-mark is more efficient. It could also mean that since AutoCAD has existed in the market longer than NavisWorks there are just simply more people with questions. In this example, AutoCAD received a higher SUS ranking than NavisWorks when answering the question "I think that I would like to use this system frequently".

I then analyzed the results of the SUS and click-count along with the software capability comparisons. The data was then input into a radial chart as shown below (Figure 13).

In general, there is still room for software improvement in the technical functionality of the hatch-mark. No one software scored perfectly in every category. Revit, for example, has the best

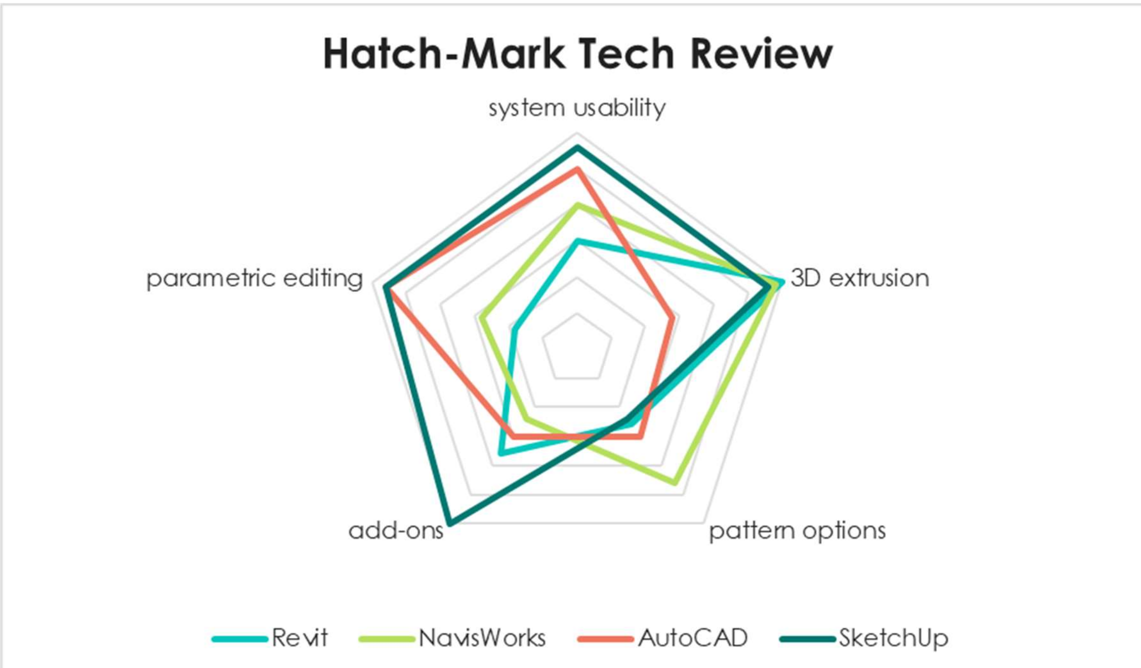

Figure 13 Radial Graph of Hatch-Mark Tech Review

3D extrusion capabilities but lacks parametric editing commands. However, this chart also shows that SketchUp is particularly versatile in hatch-mark drawing and 3D modeling, especially when the add-on features and user created system apps are considered. If a "perfect" model of the hatch-mark exists, it is most likely to be found in SketchUp. Therefore, the research focused on the SketchUp 3D modeling software as an archetype to identify missing gaps in finish trade communication.

Searching for hatch-mark models in the software was easy, as part of their subscription policy includes an open-source model "warehouse". I narrowed my search to include finishes with waterproofing systems, hoping to illustrate the system behind the finish illustration. One model stood out against all the others and shall be used as a basis for this research (Figure 14). The

International Masonry Institute's (IMI) Detail Systems translates the entire hatch-mark installation system into BIM (SketchUp Warehouse 2024).

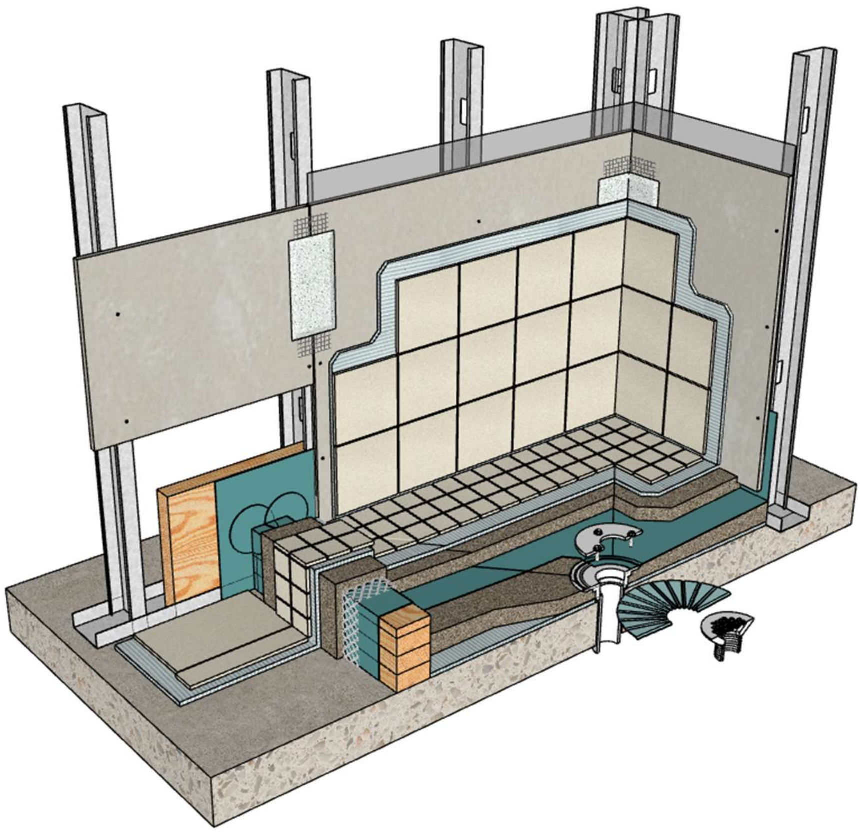

Figure 14 Shower Detail-Tile

This model was published by the International Masonry Institute (IMI) via Trimble's Sketchup and incorporates many of the previously mentioned software features. Of most interest is the incorporation of tile installation information. IMI's idea for the 3D model first emerged in 2008 with the masonry detailing series. This series focused on brick and concrete masonry units and their installation details (Throop et al 2008). The transition into the 3D tile and marble finishing series takes the technical detail specifications of the masonry models and applies them to the finishes.

As a trade involved in the structure of a building, masons have years of experience in BIM dialogue. For example, federated models showing CMU walls interacting with plumbing and electrical lines have become standard in the industry. The framework for translating a finish hatch-mark from design into the construction field becomes similar. Here we can see the hatch-mark defined to industry standards. While other models presented simplified or abstract representations, the IMI model uses detailed 3D geometry to depict every layer of construction, from mortar to finishes. This approach offers a deeper understanding of how materials interact and perform over time, essentially the function of an installation.

Unlike other hatch-marking tools, this model stood out to me in a few different ways. First, it incorporates 3D detailing that accurately represents industry-standard installation techniques. By translating complex finishes into a BIM format, the model enables users to visualize each stage of the installation process in SketchUp. If one were to zoom in on the teal waterproofing behind the tile, one would see a dimensional thickness appropriate for a vapor barrier in shower applications. Moreover, even the mortar behind the tile has standard thickness and the industry method of parallel trowel lines are laid out (Figure 15). This level of detail provides a more realistic and informative visualization of the installation process than traditional 2D drawings or basic 3D models.

The IMI Detail Systems model also distinguishes itself by emphasizing accessibility. Masonry and architectural experts employed by an educational institute authored the model. It focuses on education rather than profit. This contrasts with other models that may prioritize proprietary or paid features. This model was created with the intent to educate and to help the end-user visualize the installation materials processes that go into masonry installation (Throop et al 2008). Having a model verified by industry experts and meant to educate rather than make a profit ensures an equitable and accurate model. This notion of a model valuing education over profit is particularly relevant because while currently free, SketchUp has plans to move its open-

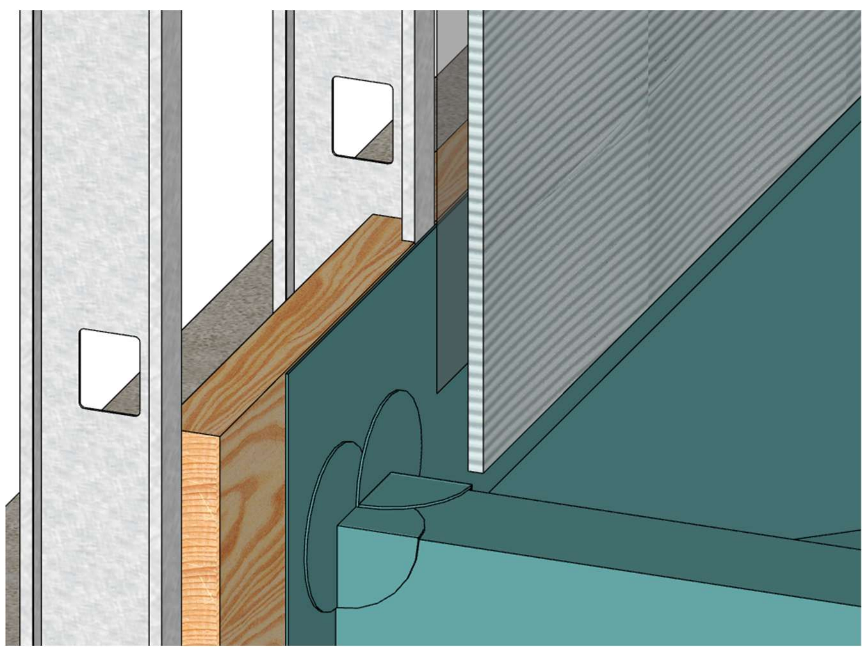

Figure 15 Shower Detail- Waterproofing

source 3D Warehouse into a subscription-based plan (SketchUp 2024). Smaller contractors with small budgets can still get questions answered. The IMI has made a commitment to free and open design help through their website. This detailing series is still new, however, and the IMI is still working on incorporating their SketchUp Series into Hive (Conwell 2024). Apache Hive is a data warehouse software that can both store and translate the systems between multiple Architectural software (Wallen 2023). This leads to the final advantage of the model, superior BIM integration.

The IMI model offers a significant advantage in terms of BIM integration and interoperability. By converting data into multiple BIM-compatible formats, the model allows for seamless coordination across various software platforms. This interoperability ensures that the model can be used effectively in the broader context of building design and construction. An architect working in AutoCAD can share these models with a steel contractor working in NavisWorks. This makes it a comprehensive tool that enables users to visualize not only the form but also the function of a finished product. The hatch-mark model remains useful across a wide range of applications, from basic construction to more specialized finish installation projects.

Method 2- Interviews

Once the technical review was complete, I had an idea of what a useful, constructable 3D hatch-mark would look like and which software had the most potential in creating and implementing it. With this model in hand, I still needed an industry framework that exemplified how models are used in constructability reviews and installation. To this end, I conducted interviews with the designer and developer responsible for creating it.

The IMI interviewees were recruited via e-mail as they are in different areas of the country, Cole Cabler on the West Coast and Scott Conwell on the East. The interviews were then conducted via Zoom. For background information, the questions first asked about their experience in the construction industry (Appendix B). These first questions helped me understand whether they approached projects from a technical, computer-based perspective or more from a field-based, hands-on approach. Cole is an experienced architectural designer with a strong background in BIM, having held leadership roles in architecture firms across Oregon and Washington. He specialized in project design, construction administration, and management before his role with the IMI. His expertise in BIM modeling is complemented by his work in urban planning and public development. This experience suggests a focus on the practical application of design, ensuring that the hatch-marks are not only visually accurate but also serve the purpose of constructability. His work in architecture and construction administration would require hatch-marks to be functional, conveying real-world installation techniques and materials clearly and effectively for both design teams and contractors.

With over 30 years of experience, Scott is a leading expert in masonry, stone, tile, and terrazzo construction. As a director at IMI, he oversees the Masonry Detailing Series and personally authored the model I found. He has extensive contributions to industry standards, technical publications, and educational workshops. His authority in the BIM and construction sectors is highlighted with recognition as a Fellow of the American Institute of Architects (FAIA) and a member of the Construction Specifications Institutes (CSI). Because of this extensive background, I found that Scott prioritized the functionality of hatch-marks. His vision of the IMI model is to use it to avoid errors and improve the buildability of designs.

Given the extensive industry experience of the interviewees, I felt confident in trusting their answers to help set up a hatch-mark criterion. Next, the questions asked about the interviewees' direct experience with BIM. This question was used to rank software preferences as well as methods. It was also used to analyze the methodology behind the IMI detail series and how they can be incorporated into the constructability and clash detection process. Sketch-up was lauded for its simple interface and scalability. This scalability enabled the authors to incorporate small details like flashing and the previously discussed troweled mortar.

In both cases, the interviewees design approach focuses more on how hatch-marks convey accurate, actionable information for construction professionals rather than purely on their aesthetic appearance. They prioritized clear communication of technical details and installation methods over decorative or purely visual elements. For example, Scott prefers a minimalist, functional style for his models. He uses an all-white background, hard lines, and simple textures in his drawings to keep the focus on conveying constructability.

This last scope of interview questions intended to gather information regarding the end-user of the detailed models. The interviewees explained to me that the end-users like architects, engineers, and other design professionals benefit from using the model in their federated comparisons. By using a 3D virtual mockup of the hatch-mark system, they can explore complex masonry conditions like air barrier terminations, flashing at corners, and grouting techniques. The hatch-mark model gives them a deeper understanding of constructability and real-world applications. Often overlooked details are represented in a 3D space, which encourages questions and discussions that help fill knowledge gaps. The hatch-mark model becomes an expert on installation merely by existing, it contains form and function.

Overall, these interviews enabled an understanding of developing a working hatch-mark model. It highlighted the important connection between technical expertise and real-world experience. The modeling workflows they developed included repeated references to standard installations. Both interviewees had an admiration for the knowledge of skilled craft workers. They underscored the importance of collaboration between design professionals and experienced contractors in construction. For example, the 3D models are constantly updated and adapted based on new technologies and conditions. A perfect hatch-mark should be designed and frequently updated with input from installers and to industry standards.

The IMI Detail Systems model represents a prototype for visualizing and understanding the function of finish trade installations. Its focus on educational content, technical accuracy, and BIM integration makes it a superior model compared to other hatch-marking tools. Now that we have this idea of the useful and constructable hatch-marked model in mind, we can begin to test it for feasibility under a mixed-method analysis. The IMI tile models discovered during the Technical Review will serve as the basis for a two-pronged research method.

In summary, my tech review had a few main findings. The chart below updates the methods chart with these findings (Figure 16). Firstly, the cross-comparison of software hatching capabilities emphasized a need for education and equitable opportunities in design. For example, the SUS results highlighted AutoCAD's central and familiar role across platforms. This also leans into the idea of efficiency, as a reduction in design time leads to a quicker return and increased communication. Efficiency comparisons showed SketchUp required fewer commands to create hatch-marks, while Revit and AutoCAD offered strong BIM integration, albeit with more complex workflows. An affordable and popular keystone software is necessary for different trades to communicate, especially the smaller ones. Constructable hatch-marks should be created with the intent to educate and evolve with industry input.

Figure 16 Tech Review Chart Depicting Findings

Secondly, the best way to illustrate form and function within a hatch-mark is through 3D design. The System Usability Scores (SUS) ranked Revit highly for 3D work and SketchUp for versatility. The IMI's SketchUp model depicts detailed 3D visuals useful for installation. There are also interoperability functions, enabling broad sharing across platforms. Interviews with IMI experts emphasized the model's constructability focus, adaptability, and the essential role of hatch-marks in bridging design into real-world applications.

5B. Case Study

Pump Stations send wastewater from local communities to be treated at a plant and released into the local environment. This project upgraded the pump station to meet increasing population demands to improve system capacity while also achieving sustainability goals. Key upgrades included the installation of new pumps, an increased capacity sewer pipe, and standby generators to ensure continuous operation during power outages. As part of this upgrade, the pump station installed a "Green Roof". Designed to reduce rainwater runoff and improve water quality, the installation also provided environmental benefits like green habitat and reduced urban heat.

Field Observations

Firstly, I gathered field observation data for the hatch-mark comparison criteria. This included a 3D LiDAR Scanning of the site. I used Leica's BLK360 laser to produce a "point cloud" that represents the area in 3D. The 3D maps created from this point cloud provided me with a clear view of the installed roof's layout that I could access and review at any time. Of particular interest to me were the vegetation conditions, as in this case they represent a very dynamic and parametric example of the "hatch-mark". I was also reminded of the ancient Egyptian drawing of the shrine and garden from the background study. It was almost like I was reviewing a futuristic version of the thousand-year-old scroll. By reviewing the conditions of the vegetation, I could gain a sense of the drainage conditions or "function" of the overall system.

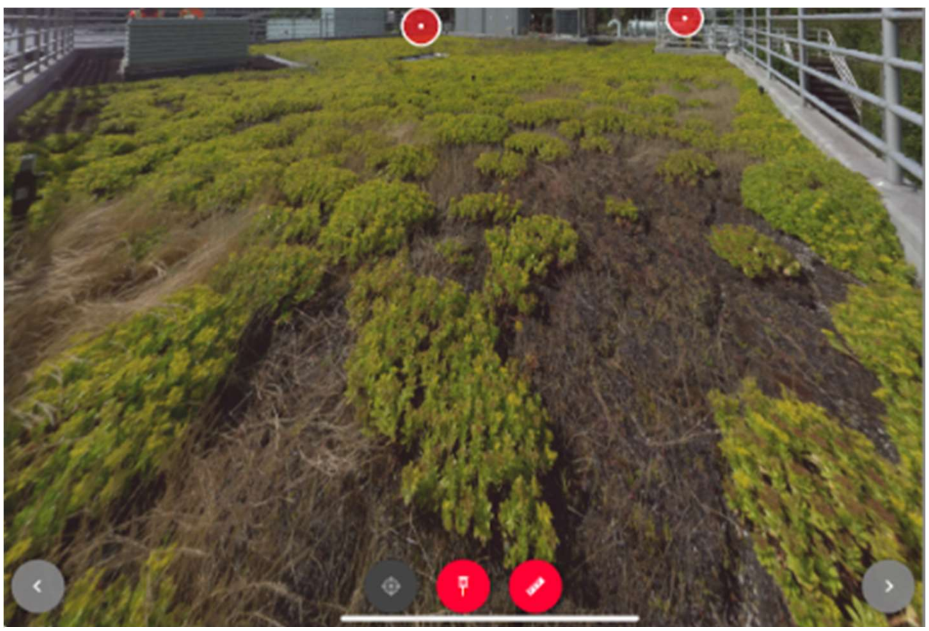

Figure 17 LIDAR Scan of Green Roof

The above picture is a screenshot I took while I was interacting with the point-cloud model (Figure 17). Unfortunately, I noted that there are large patches of dead or dying vegetation along one edge of the roof. Are the plants dying due to element exposure? Or perhaps there is a sprinkler system malfunction? Maybe there is improper drainage? A well-designed hatch-mark would provide a roadmap to answering those questions. Here is my chance to apply the hatch-mark prototype criteria gained from the tech review to provide insights into how the roof was performing.

Project Drawings

Next, the LiDAR scans of the "As-Built" green roof were compared to the hatch-marks on project drawings and design. These drawings included historical blueprints, design reviews, marked-up redlines and RFIs, as well as project documents and specifications.

I began the analysis with an archived roof plan of the pump station that was used as a basis for construction. This drawing was created in 1998 for a planned roof replacement job (see Figure 18).

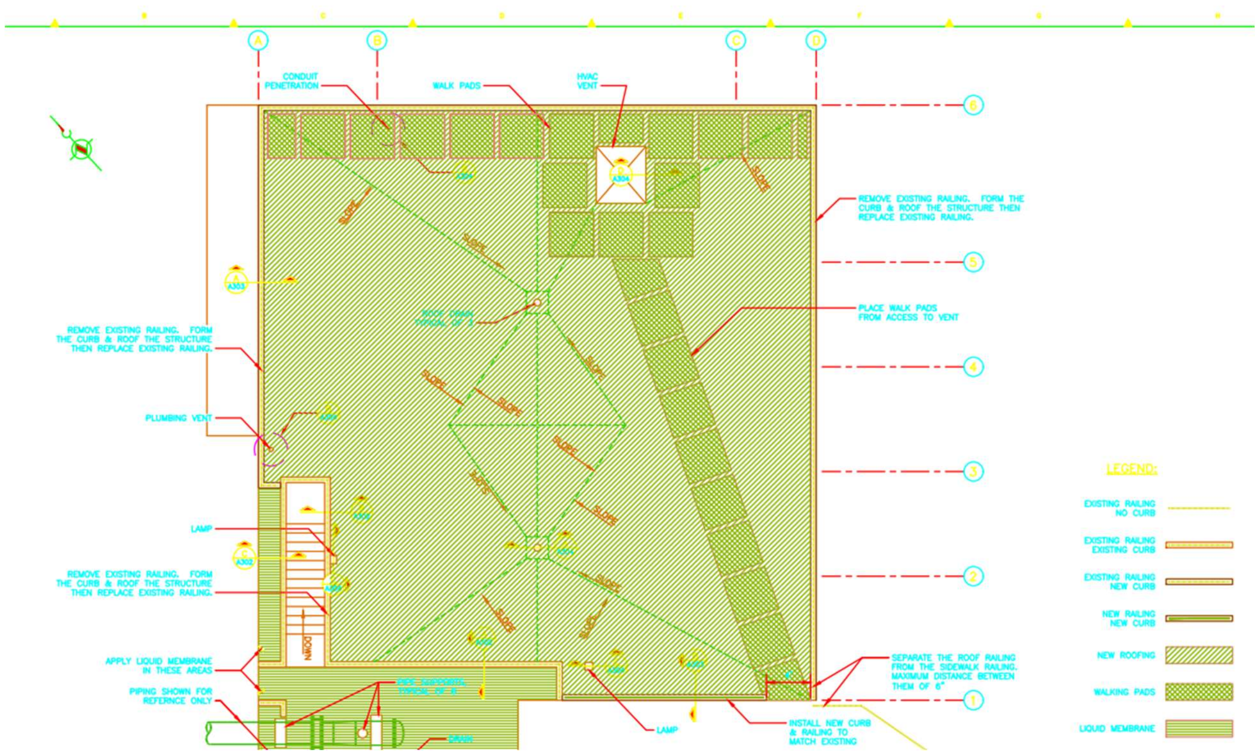

Figure 18 Pump Station Rooftop Plan View 1998

Note the Legend in the bottom right corner describing the different hatch-marks and what they represent. Liquid membrane, for example, is depicted by horizontal hatch-marks and new roofing material by an angled hatch. The walking pads have a cross-hatched design tightly arrayed in a rectangular outline. At first glance, the rectangular paver hatch-marks depicting a walkway for rooftop HVAC vent access draw concern. They mark the general location and cut of the sizes of the installation but offer no real information. Looking closely, one can see this plan view is essentially useless for the pad installers. The squares representing the pads are misaligned and the worker on the roof has questions. Is she really supposed to install the pads off-center, misaligned, and with uneven joints? Are they depicted this way because of the roof's slope, and she must figure out the proper install angle to drain away from the vent? If so, there are two different pitches to contend with and the pads might have to be cut for proper drainage. Are they shown this way because the HVAC vent specs require that area to be clear? The pad material cuts shown are centered off the vent, leaving uneven cuts on either side. This typical array of hatches does not consider the slopes on the roof, which would change the shape and cuts on the material. So many questions immediately arise, and these are stamped project drawings!

The walking pads and their hatch-marks were added to the drawing only as an afterthought, a symbol haphazardly arrayed on a page and meant to be "verified in field". Not only do inaccuracies in this drawing have the potential for more questions and slowing down production, it places an extra burden on the walking pad subcontractor to design in the field.

It is with this disappointing start that I began my analysis on the project drawings for the green roof upgrade project. Drawn almost two decades later in 2016, I was curious what changes the advancements in technology would show and if they affected the hatch-marks on the roof. While reviewing these drawings, I paid close attention to whether modern hatch-mark conventions had reduced confusion for field installers. Comparing how older and newer drawings depicted similar elements revealed whether advancements in design technology had solved past problems.

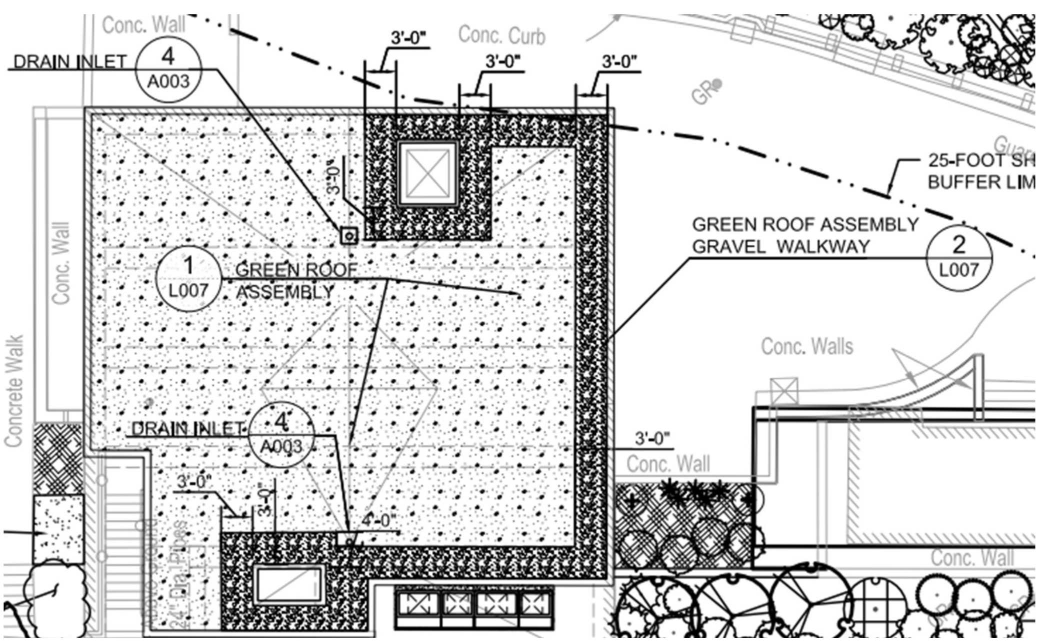

Figure 19 Pump Station- Rooftop Plan View 2018

The above plans (Figure 19) show the intended design of the green roof assembly, including updated hatch-marks. Although not a material-for-material comparison (walking pads vs. gravel), the evolution of hatch-marks in CAD is obvious. The array of gravel depicts a stone texture as a hatch-mark, making it easier to differentiate between the other areas of work. It is also hatched in a straight line, leaving no “floating” cuts and odd shapes.

Also of note is the placement of plants and drainage systems. The drawing uses a hatched array of misshapen dots and circles to depict the plants. To aid in the installation method, there is a general note for the landscapers to plant “in an equilateral triangular spacing pattern at the on center distances indicated in the drawings”. This note can be confusing and directs the reader back to an insufficient drawing. I had to dig deeper into the plant schedule to determine which types of plants had to be 12” o.c. and which were 14” o.c.

While the plan view did not have sufficient information for installation, turning to the elevations gave me a better idea of the project (Figure 20):

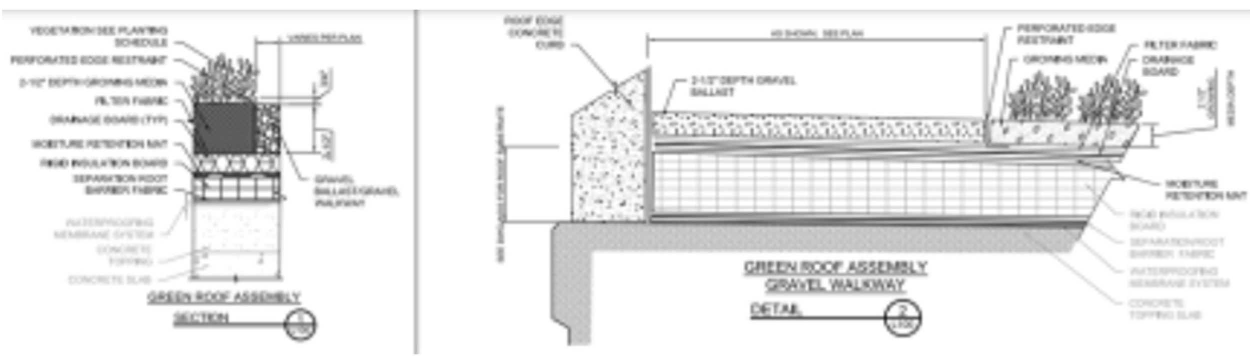

Figure 20 Green Roof Assembly Schedule

The different hatch-marks depicting the material are legible and easy to read. Moreover, the organic leaf shapes representing the plants reveal an understanding of the material on the part of the drafter. Recall again the ancient Egyptian plans depicting trees along a river. I can see the hatched plant in its final form, including the soil and waterproofing material. The specifications highlight the 3D nature of the green roof by describing it as an “assembly”. They define the installation in terms of layers, calling out membranes and waterproofing in the overall install (Figure 21):

1.4 DEFINITIONS

A. Waterproofing Membrane System includes:
1. Sheet membrane waterproofing.
2. Fluid applied waterproofing.
3. Protection layer.
4. Leveling layer.
5. Reinforced, fluid applied, polymethyl methacrylate (PMMA) flashing membrane.
6. Leak detection system.

B. Green Roof Assembly includes:
1. Separation/root barrier fabric.
2. Insulation.
3. Molded-sheet drainage panels.
4. Moisture-retention mat.
5. Growing media.
6. Metal edging.
7. Gravel ballast and vegetation.

Figure 21 Green Roof Assembly Schedule

Problems arose, however, when working out in the field. The plant assembly calls out a specific minimum of waterproofing for proper drainage. The actual building, however, was not perfectly square and the drainage outlets did not match the drawings. Digging through the RFIs allowed me to witness multiple redlined exchanges between the field and office. For example, in one RFI, the proposed roof opening could not accommodate the specified downspout install and waterproofing, and a plan had to be developed in the field (RFI #132). Another clash occurred along the waterproofed lip of the building. A 4" specified coat on the drawings was unable to be accommodated in the install (RFI# 166). These instances showed clear examples of the entire hatch assembly being unaccounted for in the field. Waterproofed layers depicted as a line in the drawings have actual dimensions and depth that can easily get missed in installation. The project stakeholders involved in the green roof assembly did not get the information they needed from the original project drawings. Because of this, I wanted to have a conversation with the stakeholders and see how they navigated the project.

Project Interviews

The interviews served as a translation both for the case study and its hatch-mark. I conducted interviews with some of the major professionals within the project itself. First, I spoke with the supervising engineer with over 20 years of experience in mechanical engineering and wastewater treatment. Next, I interviewed the project manager whose decades of field experience included serving as a general superintendent on projects. Lastly, I met with a drafter that has worked as an

AutoCAD designer for over 10 years. The interviewees were asked about their experiences when working with the green roof project and with drawings. Their range of experience supplied me with a lot of background information on how hatch-marks work in project communication, coordination, and visualization. I can use this information to identify best practices for using them to bridge gaps between design and execution.

One of the questions asked about incorporating installation methods into the drawings. This is an area where I paid attention to details about what worked and what didn't. Did the drawings and documents accurately reflect on-site conditions? Were there discrepancies between design and execution? I asked about how these real-life issues were handled and then coded in the interview data to find common themes and ideas. These themes aided in testing the newly discovered hatch-mark from the tech review and to see if it could truly aid in communication or if it created additional obstacles. For example, the drafter informed me that the drawings were made using pre-designed "blocks" for the hatch-marks. Blocks are essentially files that can be inserted into other CAD files (AutoCAD 2024). For this project, the blocks contained dynamic input commands that could flip or reverse hatch-marks. This type of command structure lent some aid in communicating the design with intent; vegetation was mirrored in the drawing for a more realistic and organic visual. However, while there is an idea of function within the AutoCAD block, there is still no true parametric influence on the rest of the structure. The hatch-marks were flipped, mirrored, and designed for an overall aesthetic appeal on the plotted page. The drawings still show the hatch-mark as form, not function. That type of communication lies within the documents and specifications. These project documents are hundreds of pages long and not readily available in the field.

To underscore my technical review, I also asked about their preferred choice of software tools. This question uncovered not just technical preferences, but also the reasoning behind those choices. Some professionals cited their preference in terms of whether it was easy to use. Others had limitations specific to project needs and budget. Coding this part of the interviews revealed recurring themes about why certain software is favored in the industry and whether it effectively supports the design and construction process. The preferred software was an overwhelming AutoCAD, both for creating drawings and for use in the projects themselves. The PM did mention that the government entity is currently transitioning the traditional documents into BIM format. It is here where he noted that they would not require the smaller subcontractors to provide 3D drawings, as it was an unrealistic expectation.

Interestingly, there was a schism in the lessons learned from the project. The engineer described the project as one that had a lot of problems, whereas the project manager described it as “straightforward”. This break in opinion could reveal the differences in project responsibilities. The engineer is ultimately responsible for the lifetime function of the pump-station, as it was his stamp on the drawings. This pump station has had some major problems with some of the mechanical equipment and water lines. The green-roof, on the other hand, was installed without issue. Interestingly, I observed in the project drawings that most of the installation and plant design was left to the subcontractor in the field. This role of the hatch-mark as a communication tool became even more important since the green roof installation was done by these subcontractors. This means the drawings and designs had to be nice and crystal clear. The RFIs regarding waterproofing were to be answered by the engineer. This could explain the PM’s view of the project as being relatively easy going while the engineer was visibly stressed by how poorly the project went.

Overall, I found the interviews agreed with my theories of incorporating better hatch-marks. The interviewees mentioned the importance of clear documentation in construction projects. For example, as a public entity, the engineer stressed their drawings and project notes can be subject to government audit. Hatch-marks serve not only as a guide during installation but also as a valuable reference for potential litigation or for future maintenance. If issues such as dead vegetation or drainage problems witnessed in the field observations occur, having hatch-marked drawings allows team members to quickly identify the original plant selections and consider alternatives that better suit the roof’s conditions. The methods chart has been updated to include the findings from the case study (Figure 22).

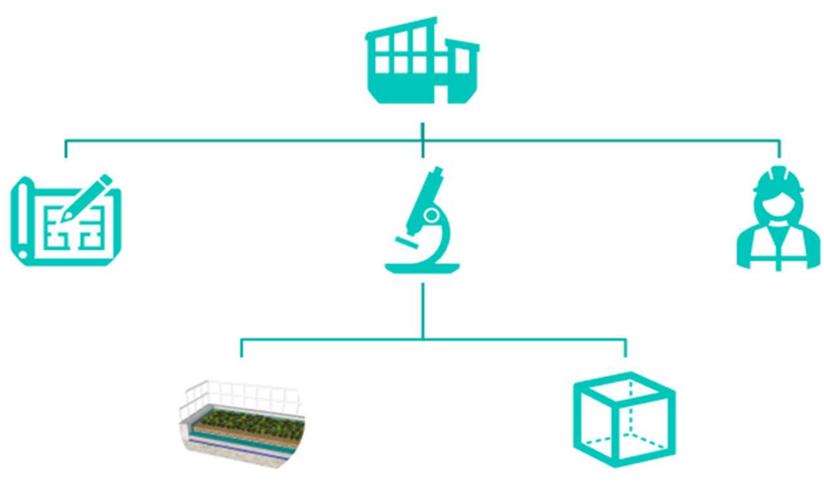

Figure 22 Case Study Methods

By combining three sources of information, I was able to create a more comprehensive view of the project and its hatch-marks. This triangulation of data revealed a hatch-mark method that could lead to better decision-making and prevent problems with finishes. In the example of the case study, this included vegetation issues and drainage problems. 3D BIM advancements in hatch-marks can minimize misunderstandings and errors. This minimization results in smoother project execution and management.

This picture of a 3D hatch-mark led into the development of a criteria. A hatch-mark needs to contain form and function, be standardized, and be freely accessible. I used the insights gained from the interviews, drawings, Tech Report, and Literature Review to establish a benchmark for evaluating future models. What improvements can be made? Are there recurring issues that need to be addressed in future versions of the software or modeling methods? The interviews provided me with this qualitative data. This glimpse into how developers interacted with these models led me to develop my own.

5C. The Benchmark Hatch-Mark

I applied the hatch-mark model criteria in a drawing created in SketchUP (Figure 23). I used the data collected from the elevation drawings for materials and installation information.

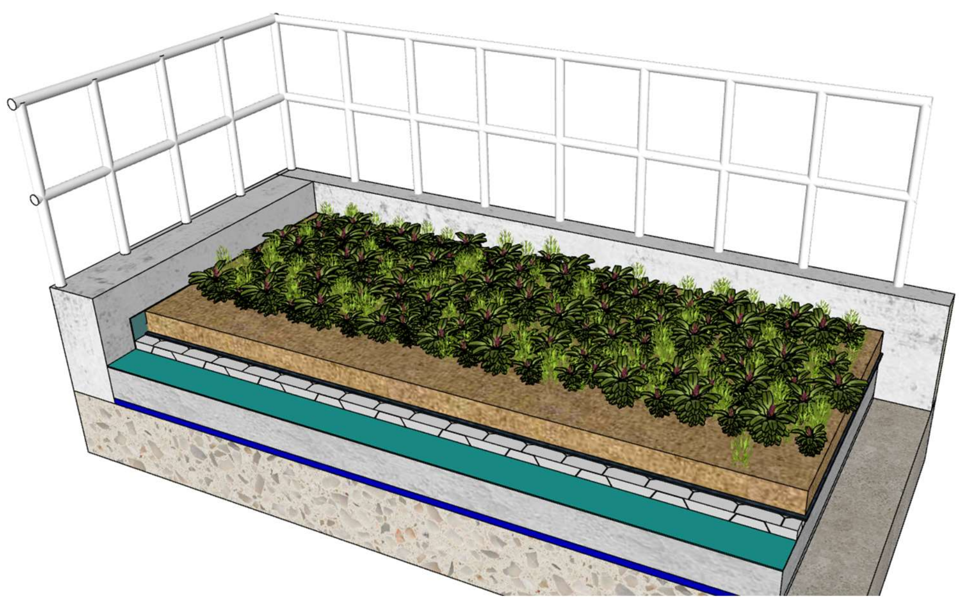

Figure 23 Green Roof 3D Hatch-Mark

This model was created with the basic design tips gained from my interviews with professionals. The background is white, and the lines are clean and simple. The hatch-marked vegetation are no longer represented as dots on a 2D plane, they are in 3D. The waterproofing systems are no longer mere lines on the drawing, they have depth and dimension. In designing, I discovered this newfound depth and dimension of the waterproofing had a parametric influence on its surroundings. For example, I had to decrease the amount of soil to incorporate the height of the waterproofing. This then meant that the root structure of the individual plant had a smaller depth for growth. To illustrate this influence, the below picture hides the soil from view and measures from the bottom of the plant to the top layer of the waterproofing system (Figure 24).

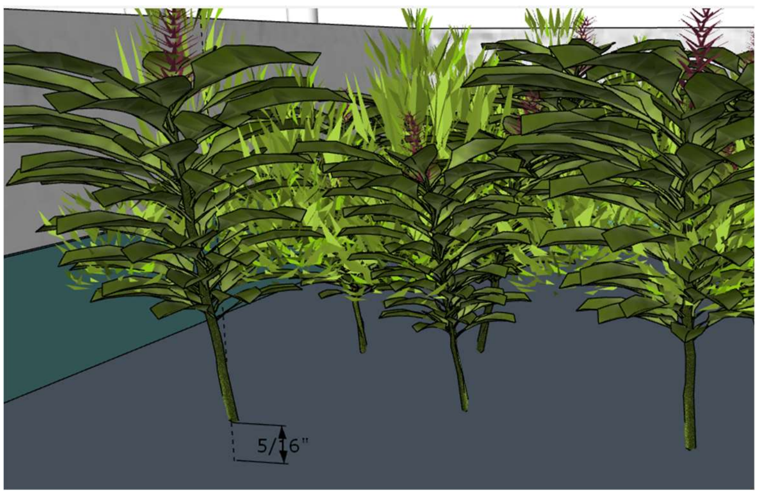

Figure 24 3D Hatch-Mark Plant Detail

This type of parametric clash-detection could have prevented some of the dead vegetation as seen in the field. Isolating the plants in situ allows trouble shooting for soil, drainage, or waterproofing issues.

Moreover, this hatch-mark answers the original research question on how it can help in the field. Recall the RFI #132 as described in the analysis of archived case study documents. The specifications called for a layer of waterproofing along the parapet and into a drain outlet. Unfortunately, the waterproofing material was too thick to accommodate the overall dimensions of the iron drain assembly. This specification was overlooked during structural design and had to be addressed in the field. My 3D hatch-mark model could have prevented this mistake. A side-by-side comparison of the two different drawings is shown below (Figure 25).

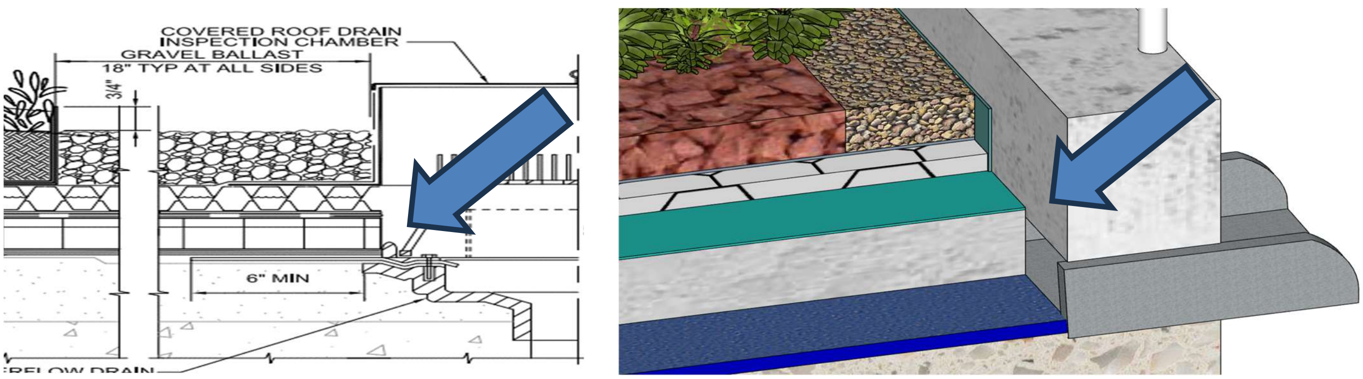

Figure 25 Green Roof 2D Waterproofing Detail vs. 3D Waterproofing Detail

The original drawings depicted the waterproofing around the drain as a single line and was not called out on the drain elevation detail, only in the specifications. It is easy to see why it got overlooked. Conversely, the 3D hatch-mark includes the waterproofing as a part of its overall assembly. In the image on the right, I was able to isolate all of the waterproofing materials into a single view for clash detection. This hatch-mark has been translated as form and as function.

Next, I incorporated the criteria of standardization into this hatch-mark. The vegetation is no longer just an image of a plant, it is arrayed via type and standard methodology. As noted in the document review, the installation instructions listed the various plants in a schedule according to type. Each type of plant had a different "on center" measurement for planting. My hatch-mark acknowledges those differences in materials and their specifications. Below plan views have been zoomed in to depict this standardization coded into the very hatch-mark itself. I have isolated each plant in turn to highlight its differences in installation (Figure 26). By transforming the hatch-mark into form and function, I can easily portray planting instructions for the installer. The very form of the hatch-mark includes information.

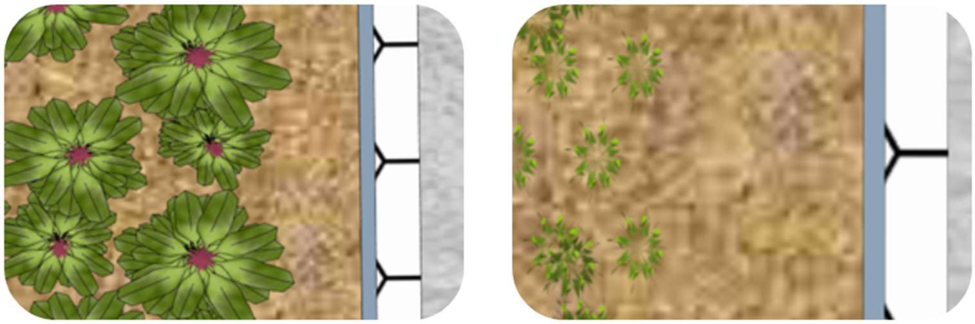

Figure 26 3D Hatch-Mark Plant Detail

Lastly, the notion of education and equitable access to these types of drawings has been embraced. The model itself was based on the IMI layers published and available for free through the SketchUp 3D Warehouse. After assembling the green roof components, I in turn published the 3D model onto the internet for free. It is now available for download by designers, students, and subcontractors for use in their own construction projects. The act of making my model available to all minimizes the impact of subscription models on the Finish Trades.

6. Discussion

The findings of the hatch-mark tech review and case study prompt an exploration into the 3D hatch-mark's usability and practical application within the construction industry.

This discussion must first acknowledge the limitations to the methodology of my research. Firstly, the Technical Review had limitations in both the scope and data collection methods. The reliance on specific software tools under the Autodesk software family may skew the findings toward these platforms. Broadening the scope from five platforms to study other hatch-mark functionalities across the industry can give a more comprehensive view of software's capabilities.

Next, I discovered that analyzing technology was an ever-evolving task, almost like trying to hit a moving target. For example, the figure below illustrates the changes made to the published IMI model just in the few months I was studying it (Figure 27). The model became more detailed and included additional specifications not previously shown. It becomes difficult to clarify definitions of a tool when that tool is constantly changing.

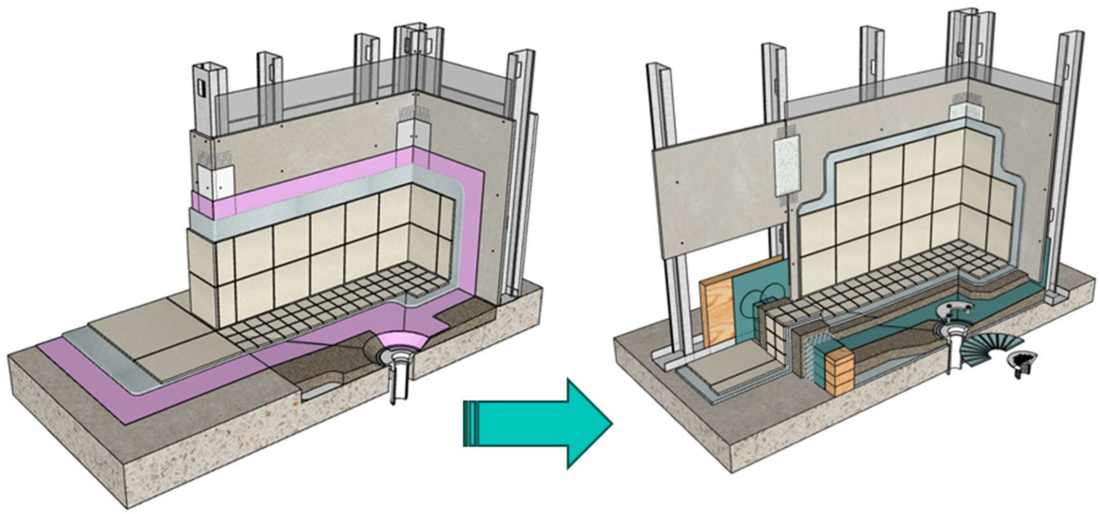

Figure 27 IMI Model Comparison

Using a Case Study also had inherent methodological limitations. Case studies by their nature are studying single entity sources for data. Further research could analyze other projects with the hatch-mark model and criteria.

These limitations suggest a need for ongoing research that encompasses a wider variety of software tools and a more diverse set of data collection methods. Nonetheless, I was still able to make some observations that can help the construction industry. These observations offered three main insights into how BIM can be shaped to cater to the detailed demands of finish design. A well-designed hatch-mark should be **3D**, **Standardized**, and **Equitable**.

6A. 3D Parametric Capabilities

Integrating finish hatch-marks into design requires better communication tools in architectural workflows. Recall the historical analysis of the hatch-mark when the drafters created standardized images for materials (such as the heraldry hatch-mark for iron). The same needs to be done now in the 3D world. To enhance design clarity means to standardize hatch-marks across BIM. It means to incorporate the means and methods of the finished material into the design process. This is where the major stakeholders and project designers take responsibility for the finishes. By utilizing the parametric model, a standardized hatch-mark can be input into a green roof or tile design that already includes the necessary layers of waterproofing. By creating these standards, architects, engineers, and contractors can communicate more clearly. This improved communication reduces the chances of mistakes and project rework.

As technology improves, the interpretation of the hatch-mark will improve. The Tech Review showed hatching works best when you create dedicated boundaries on their own layer. In other words, when you treat the hatch-mark as both **form** and **function**. As discussed in the tech review, using the "pick object" command instead of "pick point" produces better results. This is because of adjustable grips allowing you to use "associative" properties on the hatch-mark as a whole. The Literature Review showed Finish Trades work best when design is incorporated early in parametric design form. The hatch-mark gives us a language to communicate design intent, and incorporating its data into the design will serve only to help the project.

I showed in the case study how the idea of a parametric 3D hatch-mark can help with project success. I found the challenge of examining utilitarian infrastructure in light of finish hatch-marks appealing. Because of the nature of wastewater treatment, the finished product is reliant on the function of the build, not the aesthetics. Focusing on the finished trade hatch-marks in this type of case study highlighted the idea of finishes as an afterthought in design review and the need to incorporate them. This study shows even in civil infrastructure, designed without the finishes in mind, incorporating them is still important. In addition, utilities construction often requires extensive operation and maintenance manuals. This means accurate drawings for "As-Builts" are to be included for pump station operators, highlighting the importance of well-designed hatch-marks for continued water treatment.

An effective enhancement of hatch-marks can increase communication among architects, engineers, and contractors. By utilizing a triangulated data collection method, the research presented the need for integrating hatch-marks into design workflows. This intersection of theory and practice not only advocates for improved software design and training resources but also paves the way for advancements in BIM processes. Ultimately, standardized hatch-marks can streamline communication.

6B. Standardize Design

The findings stress the development of standard guidelines for hatch-mark design. If the industry takes into consideration the form and function of the hatch-mark, it is important to then also standardize it. However, the wide range of materials and specialized installations complicates this process. This leaves finishes without a consistent, formulaic approach in design. The standardization of BIM itself is still a work in progress. The first BIM standards were published in 2007 by NBIMS-US and focused mainly on the principles and methodology (NBIMS 2024). There have been a few versions since then, but project requirements for BIM were not outlined until the recently released Version 4.

Currently, there are no consistent standards for how hatch-marks should look or be used across different software programs. Moreover, only a few of the currently available software are able to even incorporate a parametric 3D design for finishes. The idea of a parametric hatch assembly is there, but not yet quite programmed into the software. For example, it was only in 2019 that AutoCAD introduced a 2D to 3D hatch conversion feature (AutoCAD 2024). This feature works through extruding a highlighted portion of a hatch-mark, then converting the 2D lines to a 3D model. The below figure illustrates the technical steps taken in AutoCAD to convert the hatch-marks (Figure 28).

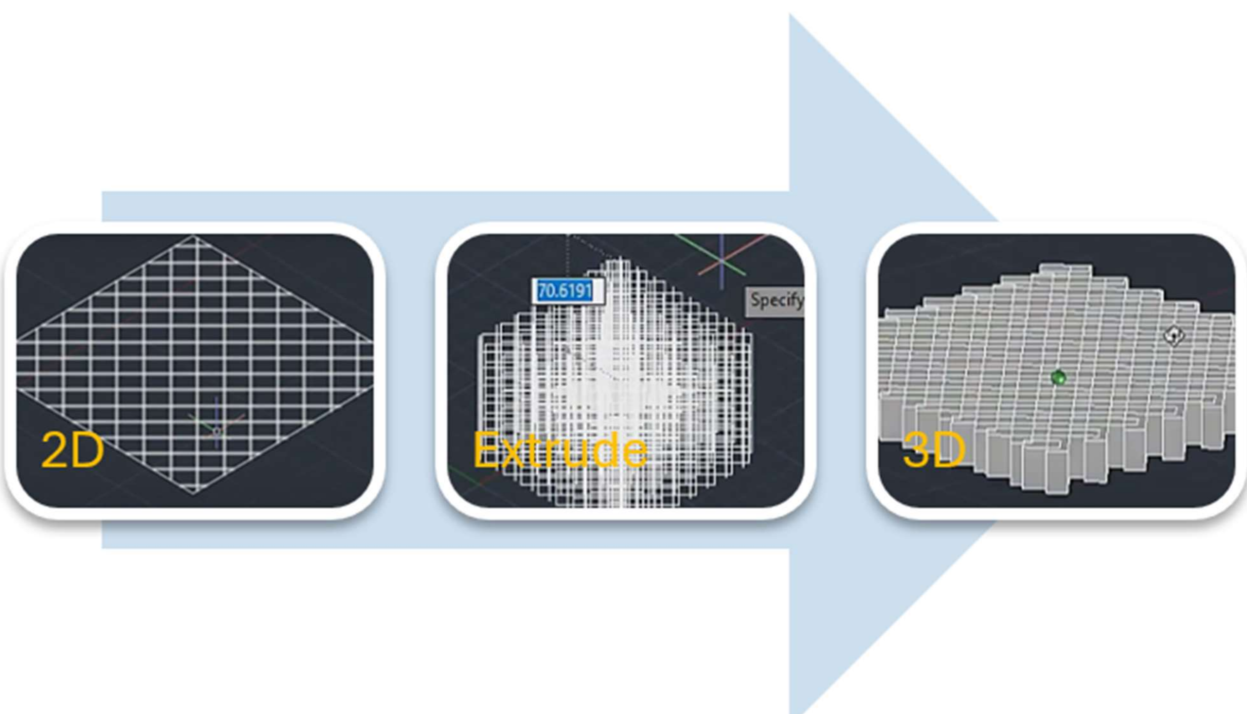

Figure 28 Converting 2D Hatch-Mark to 3D

Empowering designers means to provide them with a standardized hatch on an even playing field. By establishing these definitions, 2D hatch-mark details can be translated into feasibility reviews, allowing stakeholders to better evaluate the practicality and resource needs of various designs.

6C. Equitable Access to Design Tools

As revealed in the tech review, more hatch systems and pattern options are available for download by both SketchUp and third parties. These different material and finish software add-ons are independently published by suppliers, architects, design firms and others. The tools can be for free, for sale, or for subscription. In a sense, this market is like the old Wild West. The software developers as an industry have not evenly incorporated the technological features into BIM. An owner or project manager searching for a particular finish finds a hatch-mark marketplace with no regulations or standards. Suppliers publish their products in these 3D model platforms in the hopes the designers use their hatched-marked models and then eventually install the actual product.

At this level, design becomes dictated by the suppliers, not the builders. For example, material manufacturers are posting 3D models online via SketchUp's warehouse (a cloud database for popular construction models) and other modeling systems. A designer can finish out the 3D details of a room with a Grohe brand wide-spread kitchen faucet with hot and cold taps connecting beautifully to a single-holed Kohler branded under-mount sink. These are beautifully depicted models that easily fit into virtual renderings but could schematically cause installation problems. It is up to the individual modeler to then have the ability and/or knowledge to catch that type of incompatibility as they create the model.

These findings offered insights into how BIM can be improved to cater to the detailed demands of finish design. There is a need for tools that genuinely facilitate the design process but are also available to all. The smaller sub-contractors in the Finish Trades might not be able to afford to deliver a federated model in early design stages. But through the integration of parametric modeling, the hatch-mark can spearhead a critical shift in technology utilization for the construction industry. There could be the creation of a "generic" hatch-block. Recall the AutoCAD block function from the case study. My theory includes the same idea, a dynamic file that can be imported into a drawing. The generic hatch-block would include common finishes with system and installation visuals. If block were to be defined in a 3D SketchUp model, it could then be imported into other various software. A hatch-assembly not beholden to a corporation trying to sell products, but to the function and installation of the material itself. To empower the designer and or installer is to create a parametric hatch-assembly.

As industry software evolves, we see a trend toward subscription-based models, which can disproportionately impact smaller subcontractors and specialty trades. I discovered in the Tech Review that add-on construction tools like FieldWire, which offer 3D BIM readers and individual licenses, are more accessible to these smaller trades by not tying in complex financial models. On the other hand, monopolistic platforms like Autodesk Construction Cloud (ACC) offer more integrated apps with standardized design programs at a more favorable price point but may be beyond the reach of smaller contractors. Interviews with industry professionals revealed a preference for software like Revit, particularly in Design-Build projects, due to its wide application and functionality.

Smaller specialty contractors are often left at a disadvantage when they cannot afford or access these essential tools. The case study of green roof designs demonstrated the “verify in field” burden that especially contractors carry. It required a free model built for education by tradesmen to illustrate my theories. Benchmarking these findings against the IMI model provided insights into equitable practices for hatch-mark design. Clear and accessible tools for accurate execution should be available to all.

In conclusion, equitable access to design tools is critical for smaller subcontractors. Allowing full participation in the BIM process without the burden of costly subscription models will facilitate effective collaboration among all stakeholders. This includes everyone from architects to specialty Finish Trades. As the industry moves forward, we must foster more inclusive and equitable construction practices.

7. Conclusion

The industry has a lack of standardized hatch-mark design systems across various architectural software, which can lead to inconsistencies and errors in BIM processes. As the construction industry increasingly relies on digital tools for design and execution, the absence of a cohesive framework for hatch-mark representation hinders effective communication among stakeholders. Additionally, the proliferation of software options creates a "Wild West" environment where design choices may prioritize marketing over functionality. This disparity in software capabilities and user experiences necessitates a thorough investigation into how hatch-marks can be better integrated into workflows to empower designers, enhance drawing clarity, and promote equitable project outcomes.

The primary research question sought to explore what a well-designed hatch-mark system looks like and how it can be incorporated into drawings. By employing a mixed-methods approach that combines software analysis, qualitative interviews, and case studies, the research aimed to identify best practices in hatch-mark design and utilization. This investigation assessed the effectiveness of current software tools and their impact on design accuracy. Ultimately, the goal is to determine whether advancements in hatch-mark representation can lead to improved project outcomes and foster a more equitable design process within the industry.

The literature reviewed in this thesis focused on research that aims to streamline the selection and incorporation of finish materials within the BIM framework. This review witnessed how rapidly 3D modeling technology is evolving. I saw in the literature that many current models only focus on form or on function, which can lead to confusion. Two primary themes emerged from the research: the improvement of existing finish models and the development of new models for future application in the construction industry. In the first theme, researchers have been focusing on enhancing current finish models using innovative technologies like 3D printing and artificial intelligence (AI). These advancements aim to create more efficient cost-estimating methods that can organize the vast array of finish options, making it easier for users to access critical information such as material specifications and pricing. For example, researchers have developed AI tools that allow for comprehensive cost analysis of finish materials, improving the decision-making process in design.

The second theme revolves around refining workflows and frameworks for finish design. Many studies emphasize the integration of AI to automate the design process for finishes, offering tools that can optimize the selection and arrangement of materials in 3D models. However, much of the current research tends to focus on the visual representation of hatch-marks while overlooking their practical installation implications. This indicates a gap in the literature, suggesting that future investigations should consider how hatch-marks can effectively convey both design and installation information (**form** and **function**). By addressing these issues, future research can contribute to a more complete understanding of how to integrate hatch-marks into construction workflows. Finding better ways to combine 2D and 3D hatch-mark representations needs to happen **now**, before the industry becomes more chaotic.

The key takeaways from this study lead to some future research ideas. As the industry explores new technologies like AI and VR, designers will have better tools to make decisions about materials and finishes. This means they can choose options that are both cost-effective and high-quality, leading to better overall results. Moreover, the construction industry will continue to adopt new technologies. As software and technology continue to evolve, there are many opportunities to integrate new solutions into hatch-mark design. This research on hatch-marks can help guide the use of advanced technologies like augmented reality (AR) and virtual reality (VR). Therefore, the design of the finishes needs to happen before the installers get to the site. The major stakeholders and designers of the project are ultimately responsible for incorporating the newly defined hatch-mark at the beginning of clash reviews. This also means they should bear the costs of the improved design. This is where the equitable and educated finish standards comes into view. Installer knowledge can be programmed into the hatch-mark itself. Imagine a 3D world which makes it easier to visualize and adjust hatch-mark elements in real-time. These advancements could enhance the construction process, leading to better outcomes for projects in the future.

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Appendix A- SUS

System Usability Scale		1= Strongly Disagree	5= Strongly Agree		
Self-Assessment					
Statement	**AutoCad**	**Revit**	**NavisWorks**	**Rhino**	**SketchUp**
1. I think that I would like to use this system frequently	5	3	5	2	5
2. I found the system unnecessarily complex	4	4	4	5	3
3. I thought the system was easy to use	3	3	4	2	4
4. I think that I would need the support of a technical person to be able to use this system	3	4	4	4	3
5. I found the various functions in this system were well integrated	4	3	5	3	4
6. I thought there was too much inconsistency in this system	2	3	3	2	3
7. I would imagine that most people would learn to use this system very quickly	3	2	3	2	
8. I found the system very cumbersome to use	4	4	3	4	3
9. I felt very confident using the system	3	3	3	3	4
10. I needed to learn a lot of things before I could get going with this system	5	5	4	5	4

Appendix B-

IMI Interview questions

Questions:			
Can you explain the key objectives and scope of IMI's Detailing Series?			
What specific challenges or issues did you encounter when incorporating installation methods into the model?			
How did you determine which TCNA methods to use for different types of installation within the model?			
What methods or techniques did you employ to optimize building these models?			
Did you explore alternative approaches or software tools for modeling hatch patterns before settling on SketchUp? If so, what were the reasons for choosing SketchUp?			
Did you encounter any limitations or constraints in SketchUp that affected the implementation or representation of the series?			
Can you discuss any insights or lessons learned from the process of developing the 3D SketchUp model in relation to finish constructability?			
Are there any case studies available of the 3D SketchUp model contributing to the broader understanding or advancement of constructability in design?			
What is the future of these models? Further research needed?			