

HERITAGE DECAY VISIBLE IN HBIM MODELS

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ABSTRACT:

The research purpose aims to develop and analyse a workflow centred around decay representation within a selected BIM modelling environment. It involves conducting a comparative analysis based on accuracy criteria, process complexity, estimation of processing time, and the advantages and disadvantages of different methodologies explored. The objective of this research is to enhance the modelling process for building description by incorporating the representation of decay verified within the 3D model. The workflow proposed starts from a digital survey of a cultural heritage architecture and subsequent BIM modelling that generates significant interest within the scientific community not only from the advantages offered by the BIM process but also from the challenges encountered. One challenge relates to the complexity of modelling and unresolved interoperability issues between different NURBS and BIM modelers. Another challenge involves the time wasted in striving for a high degree of accuracy in existing models. Additionally, difficulties arise in uploading data encompassing historical information about the monument, previous renovations, material conditions, and overall state of the structure. Among these challenges, representing the decay state of an artifact within a model remains largely experimental and the paper will demonstrate the efficacy of its representation into a BIM model.

1. INTRODUCTION

1.1 General background

With advancements in cultural heritage knowledge and documentation, the creation of 3D models for historical structures has become almost a standard procedure (Yang, 2020). In this context, accurate metric deliverables are crucial, particularly when monitoring buildings undergoing restoration analysis or projects. The availability of 3D data has led to a growing interest in tools and methods that can effectively manage this information and digital data.

Building Information Modelling (BIM) is recognized as a reliable method for managing architectural design and building processes and now is almost the same for HBIM (Conti 2020). It is considered the optimal approach for collecting and integrating various data sources into a single 3D parametric model, defined as a shared digital representation of the physical and functional characteristics of a built object, providing a dependable basis for decision-making processes.

But applying the BIM approach to historical architecture remains a significant challenge, requiring the integration of multiple disciplines such as Geomatics, Drawing and Representation, Restoration, and History (Versaci, 2021). The process of modelling historic buildings within BIM environments remains challenging and labour-intensive when aiming to achieve accurate representations of highly irregular geometries. For unique shapes and elements like vaults, staircases, and others, it may be necessary to augment BIM software with 3D CAD or mesh modelling techniques. This integration becomes essential as these objects cannot be adequately represented using parametric modelling alone. Such irregular geometries require additional tools and methodologies to capture their morphology faithfully. By combining BIM software with 3D CAD or mesh modelling, a more comprehensive and accurate representation of these complex architectural elements can be achieved. However, this

integration adds complexity and may prolong the modelling process due to the need for manual adjustments and non-parametric modelling techniques. This paper focuses on the methodology employed to create a parametric Historic Building Information Modelling (HBIM) model whose key aspects include after integrating different survey and measurement techniques, verifying the achieved Level of Accuracy, creating parametric components not available in commercial platform libraries but modelled inside the software, and developing innovative methods for mapping decays by linking graphic and alphanumeric systems within the unified BIM environment (Di Luggo, 2016). The research proposal presented here concerns the construction and analysis of a workflow based on the decay representation developed within a single chosen BIM modelling software, carrying out a comparative analysis based on the criteria of accuracy, process complexity, an estimation of processing time, advantages and disadvantages of each method investigated. To do this, an integrated digital survey based on terrestrial laser scanning and photogrammetry was carried out to make a complete representation of a deteriorated seventeenth-century cloister belonging to an ecclesiastical complex built in the village of Perego, near Lecco (Moioli, 2020)

2. THE CASE STUDY

The complex of San Giovanni Evangelista is situated in Perego, a small village located on a road that connects the plains to the hills of the Valle del Curone. Perego is a fraction of the Valletta Brianza municipality, within the province of Lecco and the archdiocese of Milan.

The village is home to several historic buildings, including the remnants of a castle, a small church featuring baroque architecture, and a substantial complex consisting of a new parish church and a courtyard porch reminiscent of a cloister. The origins of the cloister can be traced back to the fifteenth century, possibly serving as a gathering place for a religious congregation (Figure 1). Before 1588, Perego was considered

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part of the Rovagnate parish. However, due to the challenging terrain and distance, the church of San Giovanni Evangelista was converted into a separate parish. According to the Urban Cadastre, two sections of the large building were sold in the early twentieth century and subsequently became the location of the Fatebenfratelli Hospital in Milan.

The Teresian Cadaster from 1873 indicates that the Fatebenfratelli Hospital owned the building following several sales among private individuals, including members of the Sovico family. Historical records, such as the census of Charles V from the sixteenth century, reveal the prominent landownership of the Pozzo da Perego family, which was later inherited by the Sovico family. This information is further confirmed by the eighteenth-century land registry.

The existing structure of the complex, except for the southern section, is likely from the seventeenth century. However, it may have been built upon a smaller pre-existing structure. The parish church, designed by architect Giuseppe Polvara, was completed in 1927, along with the adjacent courtyard featuring an eastern porch. The cloister, designed across two levels, showcases two sides adorned with arcaded porticos and elegantly crafted cross-vaulted ceilings. The fourth side of the cloister remains enclosed, creating a sense of enclosure and privacy. Ascending to the upper level, the colonnade gracefully repeats itself, creating a symmetrical and harmonious rhythm. This repetition serves as a visual and physical link, connecting one end of the cloister to the upper floor of the adjoining church.



Figure 1. The cloister, designed across two levels, with two arcaded porticos sides and elegantly crafted cross-vaulted ceilings.

3. GEOMETRICAL SURVEY AND 3D MODELLING

To obtain a comprehensive geometric representation of the church, cloister, and surrounding areas, an integrated digital survey was conducted using a terrestrial laser scanner, mobile laser scanner, and photogrammetry techniques (Figure 2). The

survey employed point clouds as metric and geometric references to create a reality-based parametric model, ensuring a suitable level of detail for a 1:50 scale representation.

The geometry of the church and cloister was captured digitally using a Terrestrial Laser Scanner (Leica RTC360) positioned at 46 points (Bernardini, 2020). The spatial sampling was adjusted based on the distance between the instrument and the objects being scanned. A low density of approximately 12mm@10m was used for the inner of the porch and arches, a medium density of approximately 6mm@10m for stairs and small rooms, and a high density of approximately 3mm@10m for exteriors. The Visual Inertial System (VIS) enabled real-time rough registration of the scans on-site.

During station positioning, efforts were made to ensure a minimum overlap of 50% to optimize targetless alignment among the scans in the postprocessing phase using Leica Cyclone Field on site and Register 360 software at home. Global registration was enhanced by removing elements that could disrupt the Iterative Closest Point (ICP) algorithm

Once the registration process was completed, the individual scans were manually cleaned to improve visual clarity and manageability of the point cloud. Points that were far from the area of interest or areas of overlap were removed. A second scanner, a mobile BLK2GO was used to survey the context of Perego just by walking. The resulting point cloud model accurately represents the complex's geometry in three-dimensional space with a high level of metric detail.

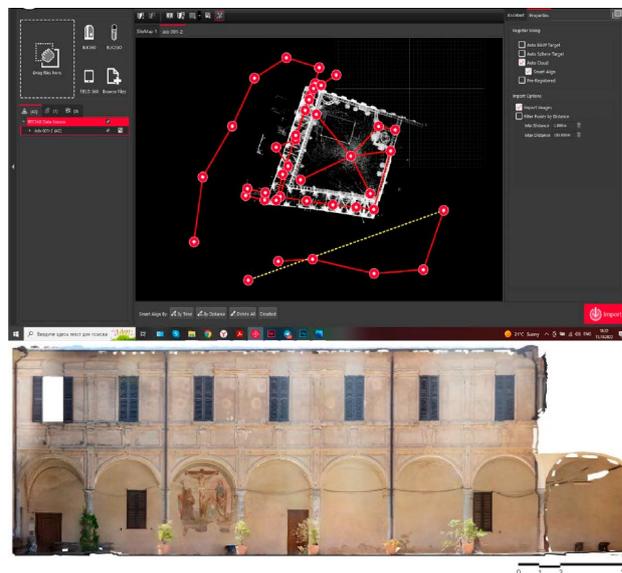


Figure 2. Top: Cyclon map of the plan of the TLS capture. Down: Orthophoto of the west facade of the Cloister

To capture chromatic details in painted parts of the cloister, which cannot be achieved through laser scanning alone, a photogrammetric survey was integrated (Figure 2). A Canon 6D Reflex camera with a sensor size of 35.8 x 23.9 mm and pixel size of 0.006 mm was used, employing an 18 mm focal length for a total of 378 photos (Nicolae, 2014).

The modelling process involved creating individual building components, such as walls, floors, and roofs, based on reference lines with different angles of incidence to determine their precise location. Default modelling tools provided high accuracy in representing the building, eliminating the need for conceptual mass modelling except for technically complex elements.

The building model was developed using multidisciplinary information from various sources, including building geometry,

material data, orthophotos, historical documentation, high-definition surveys, and other relevant data. All this information was incorporated into the BIM model (Figure 3).

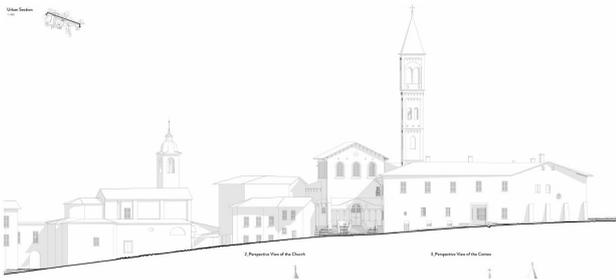


Figure 3. The whole environment modelled.

Considerable efforts have been made in the last years to create shared libraries of families and systematize their use (Parisi, 2019). HBIM involves the creation of objects using procedural modelling rules based on shape grammars (Calvano, 2022). This approach has evolved, aiming to automate the process and develop a parametric library of predefined digital objects. However, this approach raises concerns due to its misalignment with the unique nature of heritage objects that are valued for their individuality. Nonetheless, creating a parametric smart object library for common material degradations and local construction techniques can support management and decision-making for conservation interventions (Lo Turco, 2016). This demonstrates the feasibility of using BIM technology for heritage buildings by providing specific smart object libraries adaptable to any building in the area (Sampaio, 2021). Initial steps towards creating a shared library for vaults and wooden beam floors in HBIM have been taken, focusing on high geometric accuracy (Bianchi, 2016).

During the initial modelling phase, the point cloud data was imported into the modelling software, which had been previously indexed to facilitate point recognition within the modelling environment. Although the point cloud could not be edited once loaded, it could be moved or rotated. The laser scanner survey, performed using the "Leica RTC360 3D Reality Capture Solution," ensured accurate registration of the point cloud within Autodesk Revit, where it was pinned and locked in its original position.

The ability to dissect the point cloud in the modelling environment using reference planes facilitated the creation of plans, sections, and elevations of the building. This direct interaction with the point cloud in Revit allowed for achieving the desired Level of Detail (LOD) (Bianchini, 2018). To effectively organize the modelling process of diverse building components, the initial step involves conducting a semantic cataloguing of the architectural elements. This entails decomposing the building structure and identifying its distinct elements along with their interrelationships. The semantic cataloguing facilitates a comprehensive understanding of the building organism and aids in the systematic arrangement of its constituent parts during the modelling process. Several studies have explored the creation of families' libraries directly within Autodesk Revit, enabling the assignment of informational parameters and extraction of geometrical data, particularly useful for preservation works and decision-making in maintenance. These studies typically present families' libraries specific to studied historical architectural buildings. Revit provides default tools, that allows a certain flexibility in creating custom geometry (Family Editor), as well as custom parameters, that can report different categories of information, related to the architectural object (Shared parameters). In our

case Generic System Families have been used for walls, slabs, standard steps/staircases: architectural elements such as perimeter walls and levels were traced based on the indexed point cloud, followed by the placement of external loadable family elements like columns or frames.

For these last families and more detailed geometries, such as frames or profiles, a different method was employed using loadable families within the Family Editor (Rocha, 2020). Families, such as windows, doors, columns, arches, vaults, architectural profiles, handrails, decoration elements, and beam systems, are parameterized, meaning they have assigned parameters that automatically adapt the family's configuration within the model when changed (Figure 4). This parameterization enables efficient management of changes and high flexibility within the model (Oostwegel, 2022). Execution of the families with all the parameters stated above allows not only to satisfy the graphical representation of the elements within one project but also to use this family for other projects with similar rafter systems. Another advantage of this approach to the modelling is that all the parameters could be extracted to create schedules with the information about dimensions, materials and other variables or another type of parameters could be added to the family, containing information about the state of the elements and maintenance guidelines (Rony, 2022).

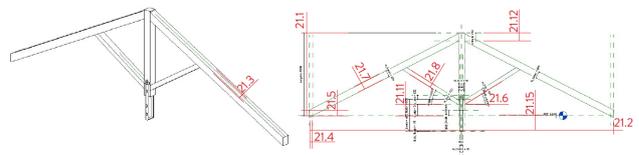


Figure 4. Rafter family: a parametric family of rafters, beams and crate created as nested family.

Some in-place components were modelled similarly to loadable families but lacked the parametric aspect. Each instance of an in-place component was treated as a unique element, which made their management more challenging. However, these components represent unalterable construction details throughout the building's lifespan, and their realization sometimes requires modelling them as in-place components instead of loadable families.

To create architectural elements like arched openings and cross vaults, two methods were checked: a model in place and an adaptive family. In the first case a method using "subtraction volumes" was employed. This technique involved excavating the masonry within the model to form the desired architectural elements, such as arched openings or cross vaults present in the courtyard porch.

In the second case the adaptive family (Figure 5) that used control points to position the vault's support and adapt its shape, resulted to have several inaccuracies and deviation, visible between the mesh and the original point cloud (Cardani, 2020).

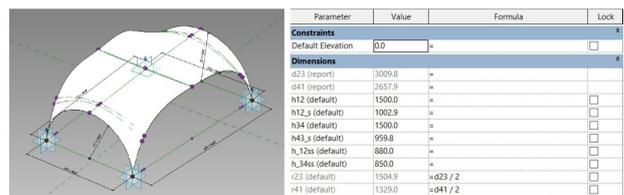


Figure 5. The adaptive family of the crossed vault and the parameters applied.

At the end of all the vault modelling, the completion of the cloister and the church was carried out (Figure 6, 7).



Figure 6. Section through the cloister, the church and the small town surveyed.



Figure 7. The modelled perspective view of the porch, ground floor, a view of the cloister and the inside of the church with the linked point cloud.

4. DECAYS ISSUE

In this chapter, we will discuss how degradation processes can be mapped within a BIM model and how this represents, despite the inherent challenges in each case, a significant advantage over traditional two-dimensional degradation mappings.

4.1 A general overview of traditional degradation mapping systems.

The traditional approach for representing material degradation involves the use of two-dimensional CAD drawings created with the assistance of orthophotos or point clouds. This method has been widely accepted for thematic mapping during data processing. The CAD file typically comprises multiple layers, each representing a specific decay. Different layers contain polylines that outline the contour and position of the decay on the façade. The software facilitates easy calculation of the degraded surface area, considering round surfaces and potential indentations through the application of a safety factor. This methodology is valued for its clear representation, distinct process, and the ability to share information internationally. Various protocols exist to describe different decay types, assigning colour or hatch patterns along with a code system. However, this methodology is limited to 2D drawings and does not allow for the connection of specific documents to individual details, which is necessary for addressing the unique challenges encountered in heritage buildings. The question of decays representation and linking data is one of the key points in HBIM (Malinverni et al., 2019). It helps to unite data and link documents to geometry, but the approaches to do so at present differ from one research to another. Moreover, as HBIM is focused on the creation of three-dimensional objects, the way to represent degradations should be different from the ones used before, with CAD tools. One possibility for 3D decay representation can be explored by attributing the alterations to main causes/factors such as mechanical erosion caused by atmospheric agents, accumulation of humidity, and chemical attack by pollutants (Delozzo et al., 2022). During the modelling phase, a code classification system can be applied to each element based on three levels of geometry. In the semantic representation stage, known features, including decays, can be assigned to each ID code (e.g., ID-code: D-01; decay: "surface deposit"; colour attributes: "blue"). Within the BIM environment, degradation patterns can be modelled as adaptive components, each associated with an ID code that provides a detailed description of the state and required interventions.

An analogous approach could be the mapping of the deterioration processes (Conti, 2020) and crack formations by constructing detailed models of the millimetre-thick surfaces using the "modelling in-place" tool. Orthophotos could be incorporated into each view to ensure a high level of accuracy. The 3D visualizations effectively depict the degradation patterns, which are associated with a range of parameters, including photographs, textual descriptions, and drawings. This approach is very time-consuming, but accurate and allows further steps in decay elaboration.

A similar method utilizing Dynamo (Reategui, 2022) has been developed in various case studies, where a reference plane parallel to the façade is established and boundaries are sketched. Running the code generates a generic model family with a thin thickness on the surface. This method is effective for mapping areas on complex shapes such as vaults, domes, and cornices. Within the BIM environment, generic elements function as adaptive components, as mentioned previously. Parameters can be assigned to each type, and data is translated into numerical values.

4.2 Testing phase

In this chapter, the testing of three methods is presented with a detailed description of the workflow and challenges that come across on the chosen path. The choice of approaches for the test phase was made according to the graphical typology and the use of the only BIM oriented software – Revit. It is important to mention, that this research aims to investigate tools of decay representation, without analysis of the conservation state of the building. The typologies of degradation patterns were chosen according to ICOMOS-ISCS “Illustrated glossary on stone deterioration patterns”, and only those that have a clear visual distinction on generated orthoimages. For the comprehensive study of decays themselves, more tests should be performed on-site.

The execution of the testing phase was impossible without Photogrammetry, which allowed to have orthophotos of the East and the South courtyard elevations. The images with the PNG (Portable Network Graphic) were imported to the Revit file as external links. The visibility settings allowed us to set the view in a way that it is possible to sketch boundaries of decays on the facades.

Adaptive Component (Figure 8): this is a versatile type of Family in Revit that can adjust its shape based on the model's geometry. Unlike traditional Revit families, which typically have one insertion point and multiple adjustable parameters, the adaptive component offers increased flexibility through geometrical manipulation and parameters. The workflow involves two stages: creating the prototype and adapting it to the facade. In the Family Editor, reference planes are set as the basis of the adaptive family by selecting "Reference plane" in the "Create" tab. At least two planes are required. Adaptive points are then created on these planes to manipulate the geometry and determine insertion points. To create adaptive points, the same tab is used, selecting "Adaptive point." In this case, ten points were created as the default number for insertion into the project.

Next, the surface of the decay is created by selecting the points and using the "Create form" function in the "Massing and Site" tab. Various types of pathologies are assigned in the Parameter tab, with names, graphics, and other properties such as area, image, and comments. These parameters can be utilized in Schedules within the project file to systematize information for the restoration report. In the second stage, the prototype of the adaptive family is loaded into the project. By selecting the desired decay type in the Family browser, Revit prompts to assign the appropriate reference plane. Then, by clicking along the pathology's perimeter, the adaptive component is placed on the surface. The position of points can be adjusted later to achieve precise accuracy.

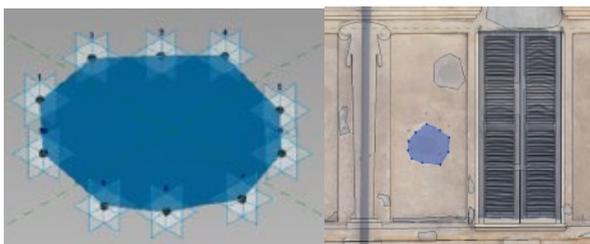


Figure 8. The adaptive family on the decay.

Generic model in-place: a generic model is an uncategorized family type that enables the creation of custom objects using basic forms like extrusion, blend, revolve, sweep, and swept

blend. Parameters can be assigned to manipulate the object's geometry and data, like other family types.

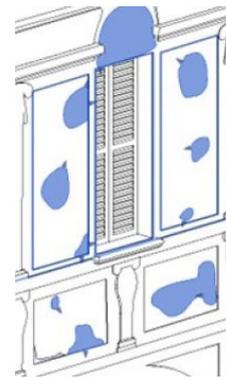


Figure 9. Generic model of one type of the decay applied on the facade.

Generic models (Figure 9) can be created in two ways: within the Family Editor or "In-Place" directly in the project environment.

When representing decay patterns on a facade, the "In-Place" method is essential for aligning the patterns to the surface. Unlike adaptive components, generic models can be created directly within the project file. By selecting "Component" in the "Architecture" tab and choosing "Model In-place," the Family Editor is activated. The desired form type and reference plane for placing the form should be selected. Using sketching tools, the desired shape can be drawn in 2D, ensuring the perimeter is closed to generate the object. Multiple objects with different form typologies can be included within a single generic model (e.g., extrusion, revolve, sweep). It is important to create separate models for each degradation typology to ensure that when selecting a specific pattern, the entire corresponding model is selected. Degradation patterns representation only used extrusion.



Figure 10. 3D model cross-section with solid fill and point cloud. West elevation with tested Generic model in-place + Filled region.

Filled region (Figure 11): it is worth noting that the filled region method in Revit, while less desirable for decay representation, is a type of annotation category used to clarify 2D drawings. It consists of a closed shape with a solid or patterned fill. Unlike the adaptive component and generic model, the filled region is limited to 2D representation and cannot accurately depict decays in 3D.

The process of creating a filled region is similar to that of a generic model. By selecting "Filled region" in the "Annotation" tab, the family editor is activated. The shape can be sketched without regard to a specific reference plane, and the object is created accordingly. It is important to note that when sketching multiple degradation patterns within the same filled region family, all elements will be selected simultaneously.



Figure 11. The sketch mode of the Filled region.

When we compare the three methods of representing Decay, we can list strengths and weaknesses for the different components. The Adaptive Components show a straightforward creation process; precise sketching tools for high precision; multiple decay types can be accommodated within one model; manual adjustments may be required for flipped families; modifications in the Family Editor are time-consuming. The Generic Model In-Place uses a simple creation process; it allows drawing decay patterns with precision; each model corresponds to one decay type for clarity; it has limited ability to be quickly modified like adaptive components; ensuring correct reference planes is straightforward. The Filled Region workflows is an easy and intuitive workflow, suitable for complex and spherical shapes, not applicable for 3D views, limited to 2D representation; the graphics parameter are available, but area calculation is not possible. To conclude: Adaptive Components have high complexity, are time-consuming, precise for various scales of decay; Generic Models In-Place have moderate complexity, accurate representation, may require several models. Filled Region are Simple and quick, limited to 2D views, suitable for specific shapes. The choice of method should consider the specific requirements and priorities of the decay representation project. A summary has been described in the table below:

Methodology	Level of complexity	Time for two facades with 4 types of decays	Accuracy	Applicability
Adaptive family	High: the creation of prototype is needed; fast creation on the façade; impossible to avoid corrections)	• 162 minutes • 110 minutes for corrections and adjustments	Depends on the scale of the decay and the number of adaptive points. For decays 250 cm 160 – accuracy is 8 cm. For decays 40 cm per 30 cm – accuracy is 2 cm.	Flat surfaces; 2D and 3D views are available; quantitative parameters are available
Generic model	Medium: models are created “in-place”; no need of corrections; it is needed to enter the family editor for any changes in the “sketch mode”;	• 153 minutes	For decays 250 cm 160 – accuracy is 2 cm. For decays 40 cm per 30 cm – accuracy is 2 cm.	Flat surfaces; 2D and 3D views are available; quantitative parameters are available
Filled region	Low: it is needed to enter the family editor for any changes in the “sketch mode”	• 65 minutes (1 type of decays)	For decays 250 cm 160 – accuracy is 2 cm. For decays 40 cm per 30 cm – accuracy is 2 cm.	All kinds of surfaces; availability only in 2D views; only graphic parameters

Table 1. Strengths and weaknesses of various mapping methods

5. CONCLUSION

Even though the BIM methodology was originally developed and optimized for modelling new buildings with geometric regularity and repetitive elements, a workflow specifically tailored for existing historical-cultural architecture with irregular shapes and unique components, often exhibiting varying levels of decay, has been thoroughly explored. To streamline the process and enhance interoperability, the degradation mapping was conducted entirely within a BIM modelling software, comparing different approaches. The advantage of mapping decay directly within the model, without relying on external tools, becomes evident in terms of time savings and consolidation of information in a single location. The model becomes a repository of data and dynamic transformations, allowing for a temporal analysis of the progression of pathologies affecting the building. Furthermore, this approach not only enables the measurement of degradation states in terms of surface area but also facilitates updates over time, making historical data available for study. The current study focuses solely on a representative methodology, offering insights into various possibilities. In future researches, the potential to catalogue or identify pathologies using shared codes could be implemented within the model itself as attributes of the defined objects. Consequently, degradation would assume the status of an intrinsic parameter of a selectable material, enhancing the model's capabilities and overall representational value.

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