reviewed paper

Urban Mining Reloaded: Scanning Building Elements with Gaussian Splatting

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DOI: 10.48494/REALCORP2026.6108

1 ABSTRACT

The construction sector is one of the largest consumers of raw materials. This consumption can be reduced through reuse and recycling of building materials and elements that have reached their end-of-life. However, there is a lack of information on the existing building stock as well as missing information on re-usable building elements suitable to be integrated into architectural design. This paper addresses both areas by presenting methods to estimate the availability of urban materials from city models and by exploring novel approaches for scanning 3d elements using Gaussian splatting. We discuss practical experiments on case studies of buildings in the city of Vienna, Austria. To estimate the material stock, 3d models (LOD 2.1 CityGML) were enriched with GIS data on building periods and typical basement heights from those periods – information which are not included in the surface geometry of the city models. From the evaluation of case studies that were surveyed with detailed representation of geometry and materials and subsequently converted into BIM models, material intensities were determined for specific building types. These data allow rough estimations of the material stock for similar buildings based on gross volume calculations. To provide resources for the re-use of building elements, Gaussian splatting as a digitalization technique was chosen to reduce the deficits of traditional methods like laser scanning and photogrammetry, which often fail when capturing objects consisting of transparent or reflective materials (e.g. glass). We present the integration of 3d objects represented as Gaussian splats into an application for early architectural design (MR.Sketch) and describe the process of converting Gaussian splats into point clouds for the use in BIM environments.

Keywords: urban mining, gaussian splatting, building stock, planning, cities

2 BUILDING LIFE CYCLES

The life story of a building usually encompasses its creation in the past, including planning and construction, its use and maintenance, and finally its eventual decay or demolition. If we also take into account the building materials used in this life cycle, it can be extended to include the origin, type and properties of the materials, their behaviour during the ageing process, and their proper disposal or meaningful recycling. Especially in today's world of resource shortage and conscious care for the environment, these considerations should be at the centre of the planning process. By using Building Information Modelling (BIM) these phases are reflected in a digital model that very often ends when the building gets demolished. This paper discusses the final phase in the existence of a building, namely its demolition or disassembly and its recycling or re-use [RASHID 2015]. The focus is on the re-use of materials and building elements that might not be considered as waste, but as valuable resources and could be integrated into the design phase of a new building. However, the planning for recycling and reuse of materials and building elements requires additional tools and methods, which are rarely present in a traditional BIM workflow. We will address some of these issues and present concepts, methods and technologies that can help to reduce these deficits.

3 URBAN MINING OF MATERIALS

The aim is to investigate how the potential of building materials can be systematically assessed and quantified. The urban mining potential of a city could be calculated using contemporary three-dimensional city models. However, despite constantly increasing accuracy in visual and geometric detail, these models lack information regarding the internal composition of materials. City models are often generated by remote sensing methods, like airborne laser scanning, photogrammetry with drones, sometimes in combination with terrestrial scanning methods attached to vehicles. These strategies allow fast updates of a surface model of an urban environment. The missing parts of the remotely sensed models are the basements and foundations and the interior parts of a building. It would be possible to integrate BIM models from contemporary digital planning resources, but the existing building stock would still miss this information. We will describe a method that allows the estimation of the material stock from an urban surface model of a building. We used the CityGML model (LOD 2.1) from the city of Vienna to demonstrate the practical application. A first approach of this method was generated by [KLEEMANN 2016], using a 2D polygonal surface, the built footprint of a building and height information stored in GIS layers as part of the Open Government Data (OGD) of Vienna, as well as estimations from experts about basement heights. The resulting calculation of a gross volume of a building for a certain building period and building use (mainly residential buildings) was used to be scaled by material intensities of similar buildings. These reference buildings were surveyed in detail to obtain a relationship between gross volume of the building and its quantitative distribution of building materials. We extended this method to calculate a more accurate gross volume from the CityGML (LOD 2.1) model (supplied by MA41, part of the city administration of Vienna), that contains a more accurate geometric representation of the roof volume. To estimate the gross volume of the basement we sampled various analogue plans of reference buildings (supplied by MA37, city administration of Vienna) to calculate an average basement height for a particular building type and building period. Further details of the entire workflow are described in [HONIC 2023], which describes some of the developed methods from the applied research project BIMstocks [BIMstocks n.d.].

To provide web-based access to the estimation of available material stock an interactive 3d application has been developed with the aid of the CESIUM library [CESIUM n.d.]. (See the web application visualization in [Fig. 1]) Hereby buildings can be selected, a 3d bar chart provides an estimation of the material distribution and the results of the calculation can be exported for further planning purposes.

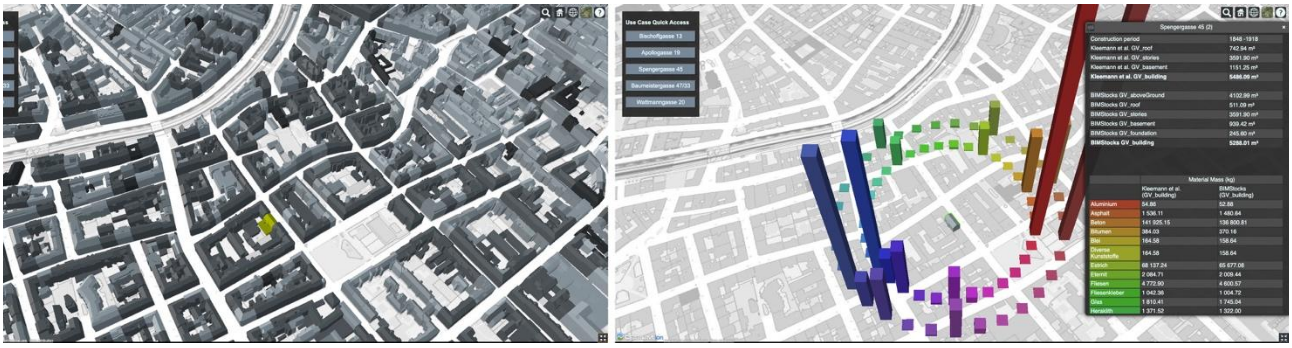

Fig. 1: Interactive web application to calculate the urban mining potential for a building in Vienna.

4 URBAN MINING OF BUILDING ELEMENTS

In the past, building materials or entire parts of buildings that had fallen into ruin or been demolished were reused for secondary purposes. This practice of using spolia can be traced back to antiquity, when decorative or structural architectural elements such as blocks, columns, reliefs, friezes, capitals or portals from destroyed or abandoned monuments were integrated into new buildings with a changed function and in new architectural contexts. Historically, the use of spolia combined economic rationality with iconographic and symbolic significance, as both material and cultural value were preserved and at the same time recontextualised. In the present day, the use of spolia not only corresponds to the guiding principles of sustainable architecture and resource conservation, but also contributes to a greater reflection on cultural heritage and underlines the continuity between historical and contemporary building practices. This raises the question of how building elements can be documented to facilitate their effective integration into future design processes. To extend the availability of reuse of building materials to entire building elements, the applied research project MHUB [MHUB n.d.] addresses several aspects in creating a web-based distribution system for that purpose. Early approaches from industrial partners, such as materialnomaden [MATERIALNOMADEN n.d.] indicate first attempts for a market for the reuse of building elements. Since our work centers on advancing strategies for recycling and reuse,from the existing infrastructure a necessity for a quick, cost effective and visually accurate method to scan building elements seemed desirable. The experience with photogrammetry in previous projects suggested this method, due to its flexible, scalable, cost effective and accurate results. Hereby images are taken from different viewing directions that can be processed into accurate 3d models consisting of highly detailed meshes with detailed color distributions stored in texture maps. However, some experiments showed that not all building elements are suitable to be scanned by photogrammetry. Especially transparent materials (like glass) or reflective surfaces (like metal) proved to be very difficult to digitize with this method. A recent development of a new methodology called “Gaussian splatting” seemed a promising approach to overcome the deficits of photogrammetry. The following sections of the paper will describe a practical approach to scan building elements with Gaussian splatting and to make the resulting 3d objects usable for design purposes in architecture.

4.1 Scanning with Photogrammetry versus Scanning with Gaussian Splatting

Fig. 2: Scanning a glass brick. Left image, 3d model with photogrammetry; right image, 3d model represented as Gaussian splats.

There are several established techniques to scan objects to create 3d models, such as laser scanning [SCAIONI 2025] and photogrammetry [FENG 2025]. However, Gaussian splatting [KERBL 2023] is an emerging new approach, with properties that elevate it from previous methods, especially in terms of visual fidelity.

As described above, a common basis of photogrammetry and Gaussian splatting is that 3d representations are computed from real, captured images from different viewpoints. While photogrammetry yields explicit geometry and textures, fitting for traditional rendering pipelines, it often fails at objects that are highly specular, translucent/transparent (see [Fig. 2] for the difference in visual fidelity and refer to [RAMIREZ 2025] for a summary of ongoing challenges) or self-emitting (light sources). On the other hand, Gaussian splatting uses implicit, volume-based radiance field data, enabling a high degree of visual fidelity in the aforementioned special cases as well. Gaussian splatting is an emerging technology, with current research aimed at both supporting capture and computations, as well as real-time rendering. Ongoing challenges include the integration of Gaussian splatting in traditional rendering and the isolation of specific parts of the scene (e.g. target objects). We will address these issues in the following sections.

4.2 Scanning Building Elements with Gaussian Splatting

We have evaluated two use cases of creating Gaussian splat representations of building elements: Capturing in-situ in condemned buildings and capturing building elements already removed and processed for re-use. The latter was possible with the help of our project partner materialnomaden [MATERIALNOMADEN n.d.], who specialize in developing processes for the re-use of salvageable construction material. The two use cases afford and require different approaches of creating input data for Gaussian splatting.

Capturing elements in-situ (e.g., doors, windows, tiles, armatures) imposes predominant constraints on the view angles and the lighting conditions. Building elements that are still mounted are obstructed by their surroundings (see [Fig. 3]), thus, depending on the environment, not all features can be captured accurately.

In contrast, building elements that have already been removed and processed can be captured with a high degree of control over the environment. This affords the ease of use of supporting equipment (lights, fiduciary markers and color control/correction tools) and the ability to capture target objects from arbitrary angles. This approach has the advantage of having references for scaling, matching parts of objects from different scanning runs and color-filtering. We will expand on these concepts in the following section.

Editors: M. Schrenk, C. Beyer, T. Popovich, J. Ryser, D. Mawlood
ISBN 978-3-9504945-5-6

Fig. 3: Rendering of the results from onsite scanning of building elements in Brush at a residential building in Vienna.

Fig. 4: Offsite scanning of extracted building elements from the stocks of materialnomaden [MATERIALNOMADEN n.d.].

4.3 Editing Gaussian Splats

Isolating a single object from a computed Gaussian splatting scene is a major challenge, since Gaussian splats do not have explicit geometry, but rather a volume of point-based distributions. During capture, the target object and its environment are visually interdependent. Shadows, reflections, refractions, light contributions may often not be attributed to a single object. Thus, editing a Gaussian splat scene for the purpose of object isolation requires a different approach from the geometry-based mesh editing workflow. To compute and edit the Gaussian splat scenes, we have relied upon standard applications, such as PostShot [POSTSHOT n.d.] and SuperSplat [SUPERSPLAT n.d.].

We have experimented with different techniques to separate target objects from the environment. Since many building elements are shaped rectangular, one effective technique is to use bounding boxes. Depending on the scene, we either set the world origin so that our target object is already axis-aligned, or we define the bounding box manually to encapsulate the target object. This way, we can eliminate a large number of undesired splats. In most cases, further depth-based and manual selection/deletion refinements allow for a good approximation of the target object. [Fig. 5]

In a second step, we experimented with color-based filtering. Capturing objects in an environment in which the near proximity of the target object is tightly controlled (e.g., a green screen backdrop), we filter splats according to their color contribution to the scene. Although this approach needs further development, early tests show promise in reducing the need for extensive manual editing.

A key challenge is that a too aggressive editing/reduction can result in unwanted visual artefacts. Object edges may become jagged, transparent objects may develop holes from certain viewpoints. Removing reflections of the original environment may result in an untrue object representation. To combat this, we proceeded in an iterative manner, filtering splats multiple times and evaluating the visual quality of target objects step-by-step. Additionally, we have created multiple versions of the same object with reduced splat counts, to optimize them for different hardware environments. Although this is a considerable workload, our goal for future development is to use the acquired insights for automating filtering.

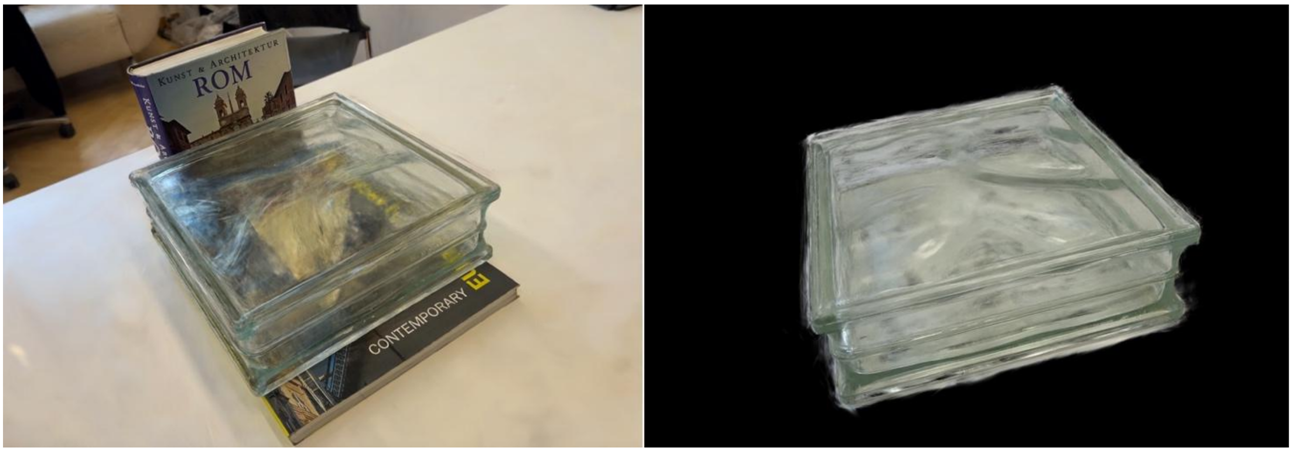

Fig. 5: Left image, original recorded splat distribution; right image, cleaned 3d model, as Gaussian splats.

4.4 Integration of Gaussian Splats into a 3D Sketching Application (MR.Sketch)

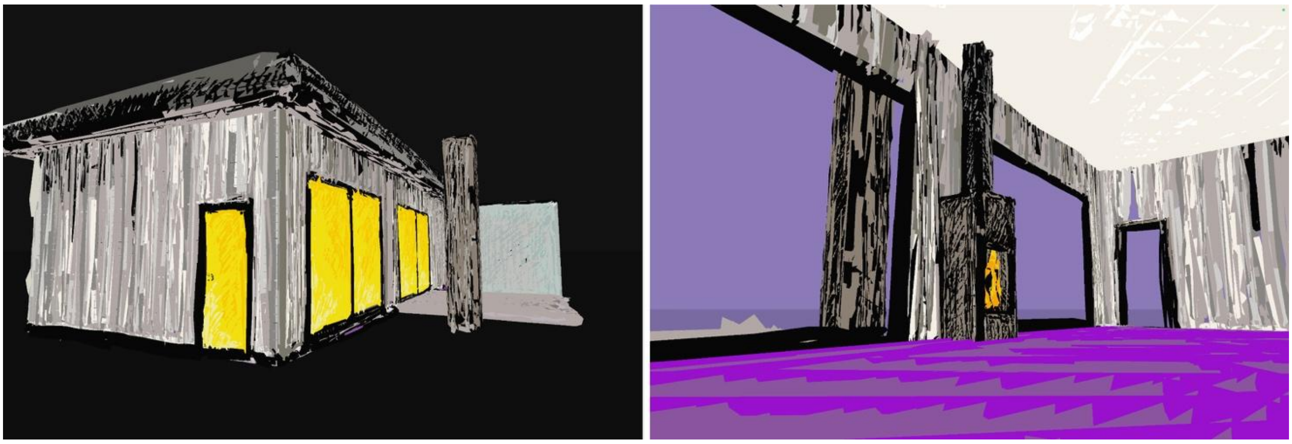

Fig. 6: 3d Sketches of a rooftop house, created with MR.Sketch.

Since our goal is to create a workflow for early architectural design, in which available building elements represented as Gaussian splats can be directly used, we experimented with their integration into 3d architectural sketches. For this task, we used our self-developed, mixed-reality capable 3d sketching application, MR.Sketch [KOVÁCS 2022][KOVÁCS 2023 A][KOVÁCS 2023 B]. This application was conceived to bridge the gap between unhindered, intuitive expression and computer aided design. It allows the creation of architectural sketches directly in 3d with user interactions akin to traditional sketching techniques. Creating architectural sketches directly in 3d enables real-time data exchange between different domain experts (structural engineers, material scientists), who can supply immediate feedback at the earliest stages of design for informed decision-making.

The user input in the application is mainly 3d freehand drawing. The designer can create 3d lines with a strong notion of where they are situated in relation to the virtual space and to the previous parts of the sketch. For this, we employed a projective drawing method, in which lines drawn on a tablet surface are projected onto a proxy geometry (drawing canvas) in 3d space. Refer to [Fig. 6] for exemplary 3d architectural sketches created with MR.Sketch.

However, traditional sketching is not limited to drawing. There are a host of techniques, such as sculpting, collage and montage, kit-bashing, etc. Using Gaussian splat representations of available building elements strongly relates to these techniques, since this approach allows combining existing elements, leading to the discovery of new spatial arrangements. The use of Gaussian splat representation allows for a flexible, yet still high-fidelity utilization of building blocks to map out the design space. Visual fidelity is of high value for this approach, as informed decisions made in the earliest design phase have the potential of a massive impact on project cost and sustainability. Deciding on elements purely by their technical details can lead to unwanted results, resulting in rollbacks, increasing cost, time and environmental impact. Therefore, our goal with this approach is to convey not just the precise dimensions, but also the visual characteristics of available building elements to support informed decision-making at the earliest possible time in the architectural design process.

4.5 VR Visualisation of Gaussian Splats and Sketched Buildings

Fig. 7: Rooftop house: design proposal with a 3d sketch combined with elements as Gaussian splats, visualization in virtual reality.

One of the benefits of creating sketches directly in 3d is the possibility of visualizing the design concepts from multiple perspectives as well as in multiple scales, with different technical infrastructure. One highly effective approach is virtual reality, since this affords the designer the possibility to experience the structures and spaces in a 1:1, real world scale.

However, visualizing Gaussian splats in virtual reality is challenging, since the original technique of rendering is optimized for a single viewpoint/camera pose. In contrast, virtual reality requires two slightly shifted viewpoints to be rendered with adequate precision and low latency. We have based our experimental visualization application on the Gaussian Splatting Virtual Reality rendering package for Unity [GSVRUNITY n.d.].

Rendering a high number of splats comes with a high computational demand. Furthermore, inconsistencies in depth between the viewpoints, as a result of the sorting of the splat locations at render time can result in visual artefacts. To address the issue of achieving suitable latency, we have made scene-specific adjustments to the density of the computed Gaussian splats. Our goal was to reduce the number of splats, while retaining the visual characteristics of the building elements to a degree that is still suitable for design-oriented decision making. Although this approach currently involves considerable manual fine-tuning, it still can be considered as a proof of concept for the proposed workflow. A frame from our experimental virtual reality visualization application is depicted in [Fig. 7].

Ongoing development efforts focus on the automation of design goal specific reduction of Gaussian splats. As for the sorting issue in virtual reality, our observations yielded the conclusion that although depth related visual artefacts can be a distraction, it does not impede the design process. Our goal is to address this issue as well, but the priority in the given context is low.

4.6 Conversion of Gaussian Splats into Pointclouds for the integration into BIM

Unfortunately, the current CAD and BIM software landscape does not support the use of Gaussian splats in their applications. Maybe this situation might change in the near future, at the current moment strategies to convert this new form of 3d representations to more widespread 3d formats is a necessary strategy for further planning and design methods. If the generation of splats is dense enough and their volume small enough a conversion to point clouds is a feasible strategy. Of course, this will result in a diminished visual quality of the appearance of the 3d object, but pointclouds are widely supported. We implemented a python script that converts each splat to a point in space, the color of the spherical-harmonics parameter is determined from its omnidirectional diffuse component. The resulting export as ASCII XYZ file can easily be imported in BIM software (e.g., ArchiCad) or 3d Modelling software (e.g., Rhino).

The example below [Fig. 8] shows the use of imported pointclouds, converted from Gaussian splats into ArchiCad. They were imported as Library objects, which allows an instantiated placement into an architectural design.

The building displayed is the sketched version of a Rooftop house, designed by Ingrid Erb with the integration of Gaussian splatting elements, like the glass door and the sink, in their pointcloud representation.

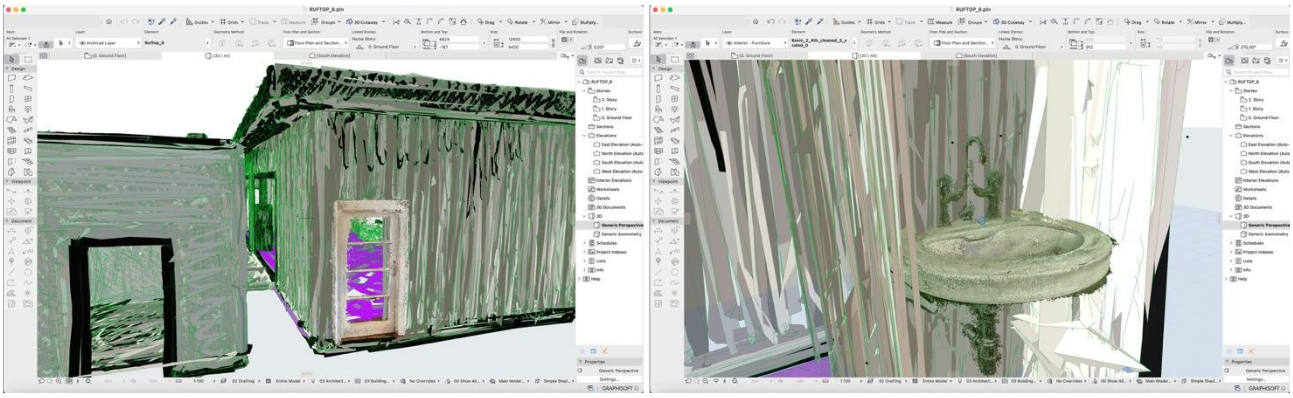

Fig. 8: Integration of building elements, converted from Gaussian splats to point clouds, into BIM software (ArchiCad).

5 CONCLUSION

We introduced several methods that can aid in generating urban mining infrastructures. Urban mining potential of materials could be estimated by evaluating gross volumes of buildings and suitable material indices. To increase the accuracy of material indices more samples of older building stock need to be performed. This might create necessities for destruction free sampling methods and fast and accurate scanning of the interior of buildings, while they are still occupied. For the integration of existing building elements, we introduced the application of Gaussian splatting for scanning building elements with a particular focus on transparent materials. The results of these experiments are very promising, as these high-fidelity visual representations can be used in an iterative design process consisting of early architectural sketching and virtual reality explorations. However, there is currently a lack of support for Gaussian splats in the contemporary BIM and CAD software. To address this issue, we provided a pragmatic approach by converting splats into points. Finally, the integration of building life cycles into urban planning will require more research activities and the improvement of four-dimensional city development strategies.

6 ACKNOWLEDGEMENTS

This research was conducted within the research projects m-hub, ACD, BIMstocks:

- m-hub: funded by the FFG – Österr. Forschungsförderungsgesellschaft mbH (National) Technologien und Innovationen für die Klimaneutrale Stadt 2023 Österreichische Forschungsförderungsgesellschaft mbH (FFG) (5124560)[MHUB n.d.]
- SFB ACD: funded by the Austrian Science Fund (FWF) project F 77 (SFB “Advanced Computational Design”)[SFB ACD n.d.]
- BimStocks: “BIMstocks – Digital Urban Mining Platform for assessing the material composition of building stocks through coupling of BIM to GIS”, which received funding from the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology through the Austrian Research Promotion Agency (grant number: 879401).[BIMSTOCKS n.d.]

We would like to extend our gratitude to all members of the m-hub research project [MHUB n.d.] for enabling the research described in this paper. We would like to give special thanks to our project partners materialnomaden GmbH [MATERIALNOMADEN n.d.], who provided valuable input for the topics of this paper.

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