engineering proceedings

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Proceeding Paper

Analysis of Suitable Roof Designs for PV Panel: Case Study of Housing Roof in Gorontalo †

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† Presented at the 1st International Online Conference on Buildings, 24–26 October 2023; Available online: https://iocbd2023.sciforum.net/.

Abstract: The demand of PV on roof installation in household sector is increasing. In this paper, an investigation in optimizing the energy performance of PV on housing roof is conducted. Three housing roof designs found in Gorontalo city are selected as the mounting planes for PV on roof. The designs represent stacked gable roof, complex gable roof, and complex hip roof. The purpose of the research is to find which roof shape is better for PV mounting in terms of sun radiation gain and access, mountable spaces, and orientation flexibility. This research employs Rhinoceros 3D to model the three roofs. The models are designed to face 12 directions from 0° to 330°. Radiation analysis using Ladybug is utilized to study the roof performance in obtaining solar radiation in all the 12 directions. It is found that the complex hip roof has more evenly distributed solar radiation on the roof planes, flexible for PV mounting in any orientation, but few mountable spaces. The stacked gable roof has 2 out of 4 suitable planes to gain solar radiation, but they are spacious. The complex gable roof has only 1 out of 5 suitable planes since they are are prone to self-shading and narrow. Overall, stacked gable roof provides a better option for PV installation compared to the other roof shapes.

Keywords: housing; mounting space; PV on roof; roof space; solar radiation gain

Citation: Djafar, A.G.; Pratiwi, N.; Rahmayanti; Mutmainnah, N. Analysis of Suitable Roof Designs for PV Panel: Case Study of Housing Roof in Gorontalo. *Eng. Proc.* **2023**, *53*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: 24 October 2023

1. Introduction

Indonesian government has set a national energy plan to use of a minimum of 25% of the roof area for building solar power plants roofs on residential buildings [1]. However, roof of Indonesian housings is varied in design. There is no specific instruction in the obligation to install solar panels on roof. People will be facing problems such as where should they put their renewable energy facilities on their house. Housing developers construct their housing roof in a variety of roof shape to attract buyers. Some of them are irregular roof shape, and become a hindrance for PV on roof installation [2].

There are many researches on the potential of PV roof to generate energy with the emphasis on roof shapes. Barbón et al., found a general algorithm to optimalize the deployment of photovoltaic panels installed on irregular flat roof shapes. The algorithm takes into account the irregular rooftop shape, the self-shading of photovoltaic panels, and some essential variabels [3]. Bayón et al. provided the optimal distribution of PV panels on rectangular rooftop shapes. [4]. Moreover, Ioannou et al. presented the optimal configuration of the PV panel rows installed on a square rooftop shape [5]. In addition, Barbón et al. [6] determined the optimal distribution of PV panels on simple shapes of rooftops. Unfortunately, researches with the topic of PV on roof mentioned above, consider only a flat rooftop as the place to set up PV.

In terms of PV on housing, Esfahani et al., find shed roof gains maximum solar energy in Perth Australia [7]. However, shed roof is a simple 1 plane roof, and can hardly be found in Indonesia's housing. Hachem et al. conducted a study on the effect of housing geometric form on façade BIPV solar potential [8]. The research did not consider PV on the housing roof. Palmer et al., identify the most suitable buildings based on roof shading but does not take into account the roof shape [9].

The previous articles deal with the optimalization of PV panels on regular rooftop shape, and regular pitch roof shape. There is the need to study PV installation on the irregular pitch roof shape. This paper discusses PV potential on the complex shape of housing roof found in Indonesia. The aim is to evaluate suitable roof for PV installation on common housing roof style found in Gorontalo, Indonesia, with addition the influence of the annual Sun movement around the equator.

2. Materials and Methods

Three complex designs of housing roof are selected to assess the suitability of PV panel installation as can be seen in Figure 1. They are stacked gable roof (A), complex gable roof (B), and complex hip roof (C). Stacked gable roof is the most roof type found in housing of Gorontalo city [10]. Roof A is consisted of 3 rectangular planes, and an irregular plane. Roof B has a rectangular plane, 2 trapezoid planes, and 2 irregular planes. Roof C has 4 trapezoid planes, and 2 irregular planes. Roof A and B have a higher roof part and providing shade to the lower roof part. Planes on roof A only face 2 directions, while B and C face 4 directions. Each roof shapes have advantages and disadvantages for PV installation. Rectangular planes provide fittable shape for the common rectangular PV panel. While PV panel is more difficult to fit in trapezoid and irregular plane.

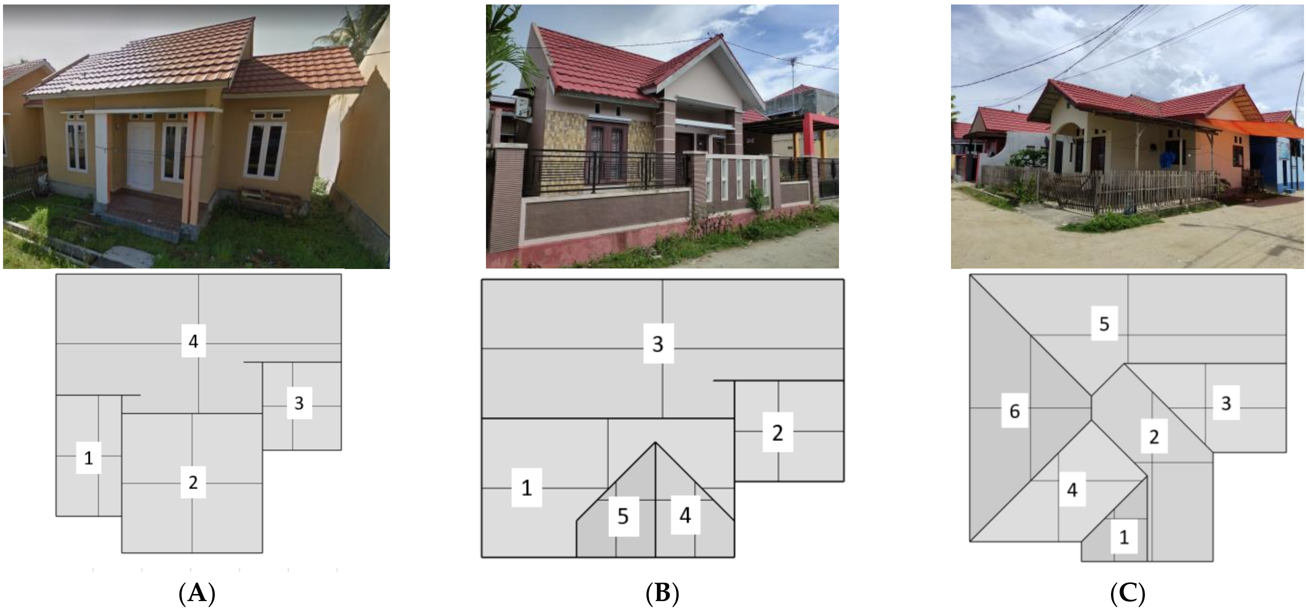

Figure 1. Housing found in Gorontalo city, and the roof plan. Roof (**A**) is stacked gable roof, (**B**) is complex gable roof, and (**C**) is complex hip roof.

Prior to this study, an investigation on the best roof orientation in Gorontalo show West facing surfaces obtain the most solar radiation compared to the other orientation [11]. Housing roof could be facing any direction, but among the 3 roofs, roof B and C have the favor of one of its planes to face West. However, even though the planes are facing West, the existence of self-shading on roof A and B could reduce the annual solar radiation gains. Therefore, a study of solar radiation gains on several directions of the selected housing is necessary to find out which roof shape provide the most suitable space for PV installation on roof.

The study in this article deals with radiation gain on pitch roof under the following conditions: (i) irregular roof shapes; (ii) self-shading of the roof; (iii) roof orientations. The roofs performance will be simulated using Ladybug's components in Rhinoceros 3D. Simulation flow can be seen in Figure 2. Roof models are set to face 12 directions from 0° to 330°. In this paper the directions will be expressed in azimuth (0°, 30°, 60°, 90°, 120°, 150° −30°, −60°, −90°, −120°, −150°, 180°). Simulation is done for a year-round analysis, from 6 to 18. The performance indicator is annual solar radiation (kWh/m^2) falling on grid points of roof planes. The grid size is 0.5 m, the visualization of grid size on roof plane is given in Figure 3. Each plane from a roof is numbered, thus the performance of each plane is comparable. The simulation results of each roof types and orientations plotted into box and whisker charts and then compared. To analyse the plane for mounting capacity, a packing method is employed to determine how much PV can fit in a roof plane. A 550 Wp panel (size of 2279 mm × 1135 mm) is selected as the size to fit in the plane area. The above analysis objective is to find which housing roof shape provide more consistent solar gain, and which roof shape provide more space for PV panels.

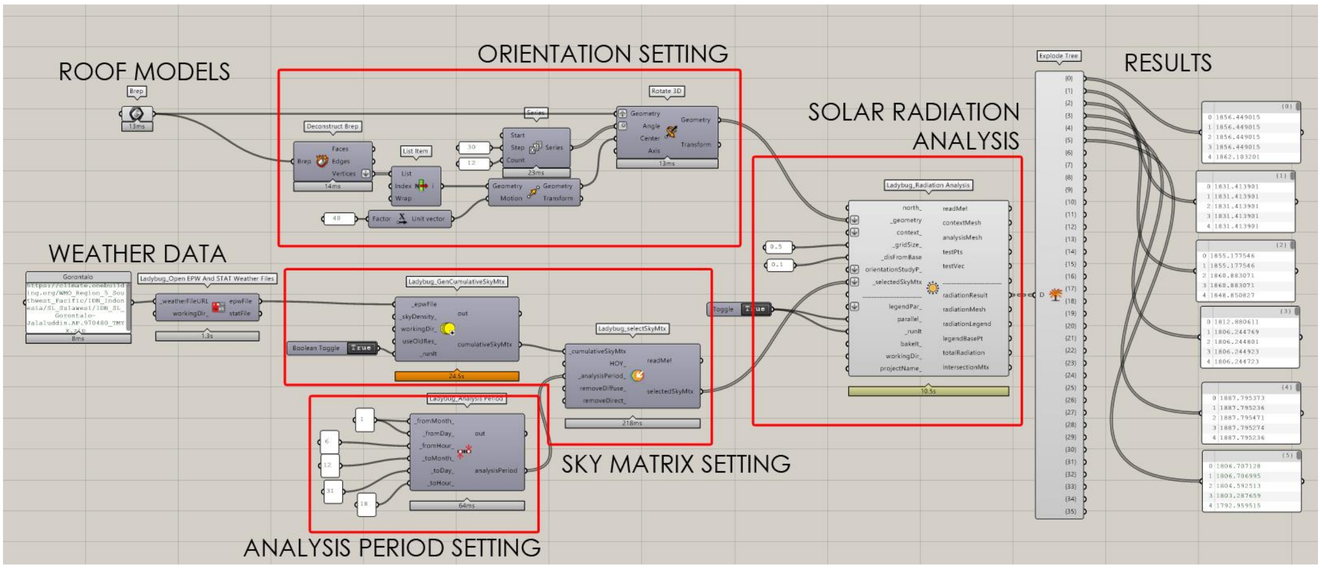

Figure 2. Simulation flow using Ladybug.

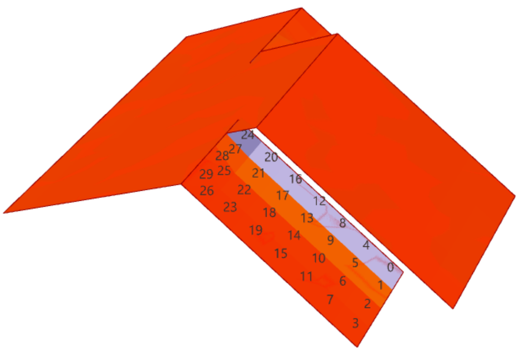

Figure 3. Grid points with the grid size of 0.5 on plane 1 of roof A.

3. Results and Discussion

Analysis of Suitable Roof Design for PV installation is discussed in 2 subsections. The first part reviews solar radiation gain on the planes of the 3 housing roof designs. The second part examines the mounting capacity of the roof planes.

3.1. Analysis of Solar Radiation Gain

The comparison of simulation result on 12 directions can be seen in Figures 4–6. From the charts below, it can be noticed that the annual solar radiation gain on plane 1 in roof A have a wide span of value ranging from 106 to 1961 kWh/m². Plane 3 in roof A also delivers quite the same result, from 150 to 1946 kWh/m². Likewise, plane 1 in roof B has varying values from 106 to 1961 kWh/m², while plane 2 in roof B from 152 to 1955 kWh/m². On the other hand, there is no specific plane in roof C which has such large interval of values. Even though on different directions, the solar radiation gain on the planes of roof C show different result, the values are generally ranging from 1715 to 1963 kWh/m².

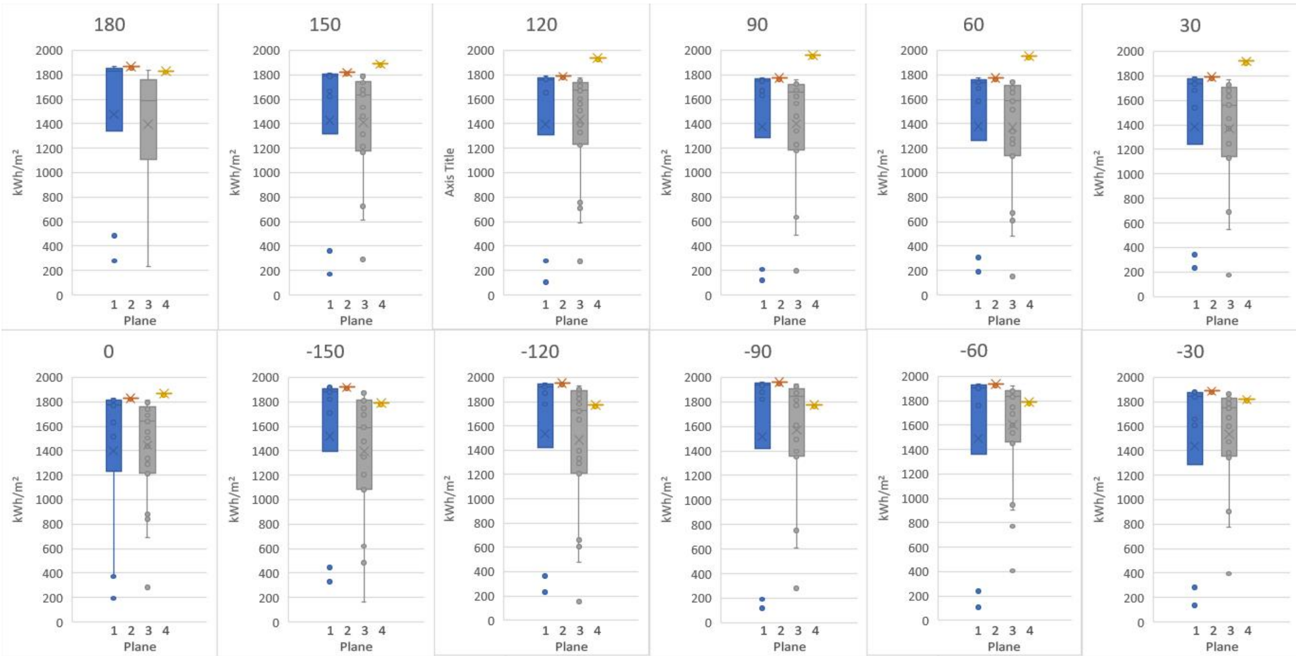

Figure 4. Annual solar radiation gain on Roof A.

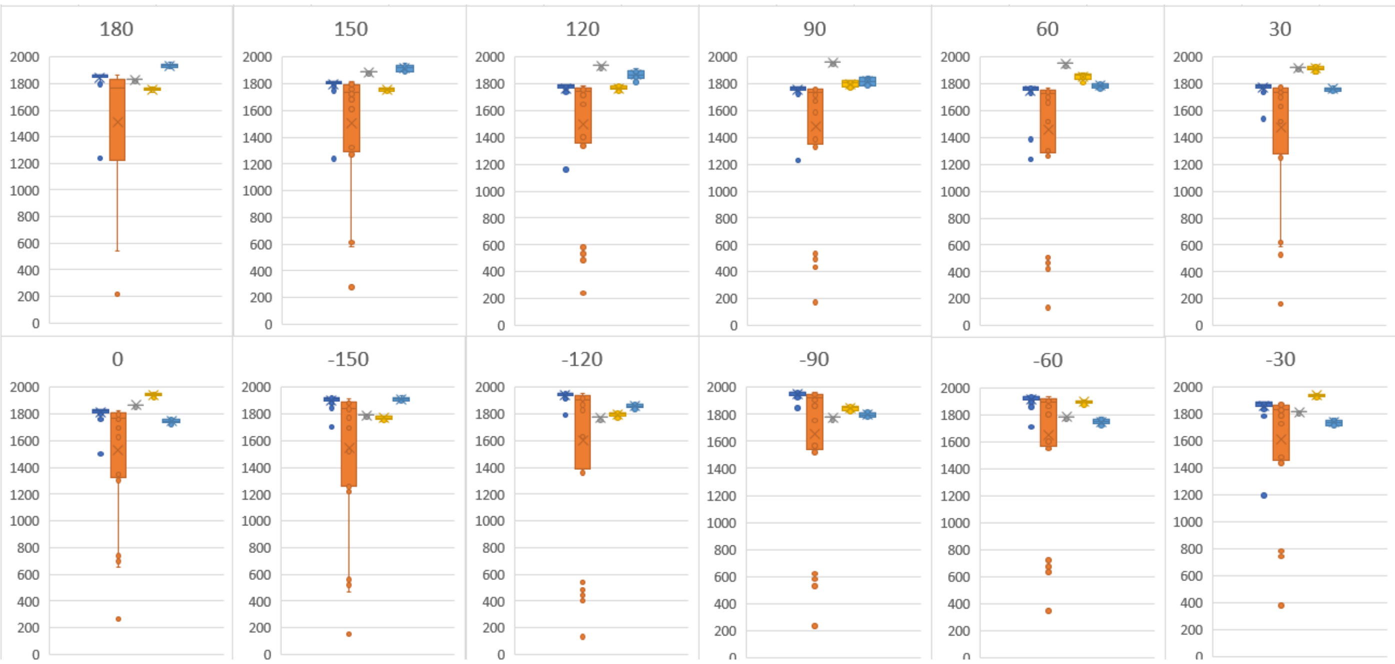

Figure 5. Annual solar radiation gain on Roof B.

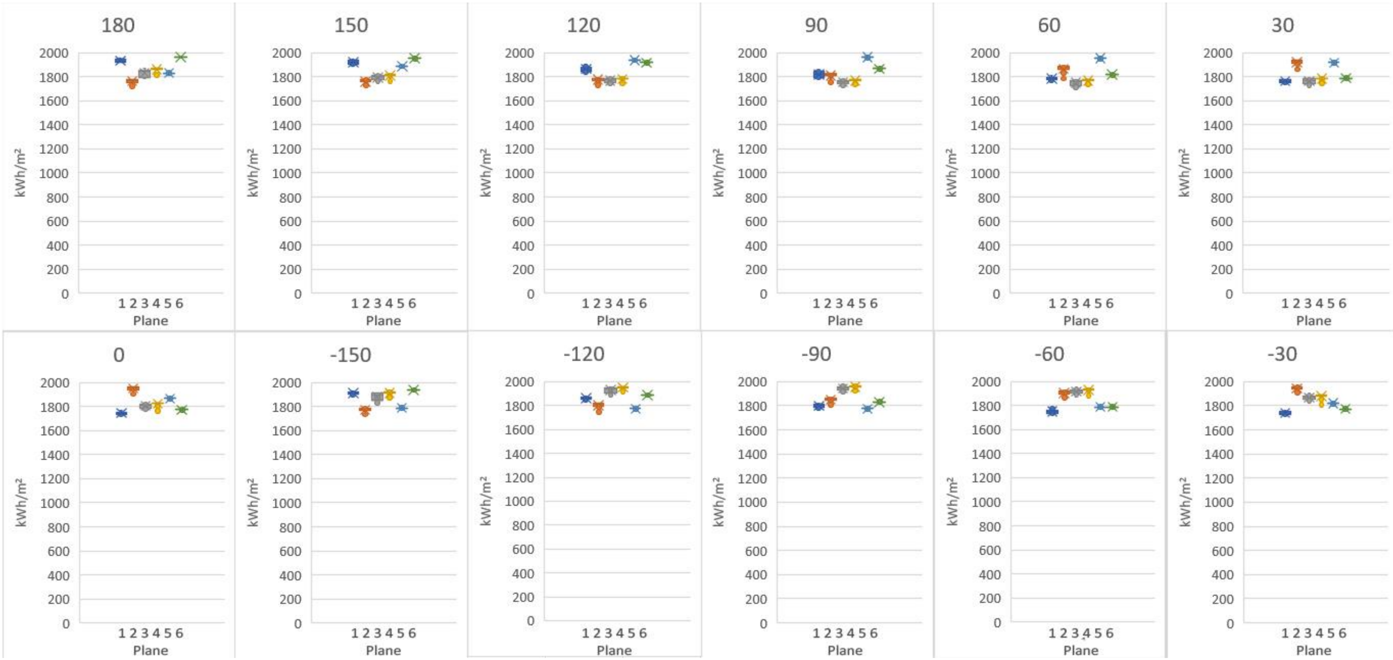

Figure 6. Annual solar radiation gain on Roof C.

The enormous deviation of solar radiation gain in roof A and B is provided by the effect of self-shading. The inconsistency of solar radiation gain on plane renders the roof solar performance low. It is preferable to install PV panel on roof with lower deviation to maximize energy production. Consequently, plane 2 and 4 are recommended as PV installation plane for roof A. Plane 2, 3, and 4 are recommended for roof B. As for roof C, there is no self-shading effect found on the roof, all of the planes are acceptable for PV installation.

3.2. Analysis of PV Mounting Capacity

There is only a slight difference of solar radiation gain in different orientation of roof C which promotes it as the high-performance roof compared to the other roof design. However, when it comes to PV mounting, there are unmountable planes due to the trapezoidal and irregular plane shape in roof C. Roof planes for PV mounting are selected based on the area with no self-shading. As can be seen in Figure 7, there are more space to mount PVpanels on roof A compared to roof B and C. The utilized method of PV packing on roof as demonstrated below is still lacking, as some occupable space is not filled with PV panels. Still the results favor roof A.

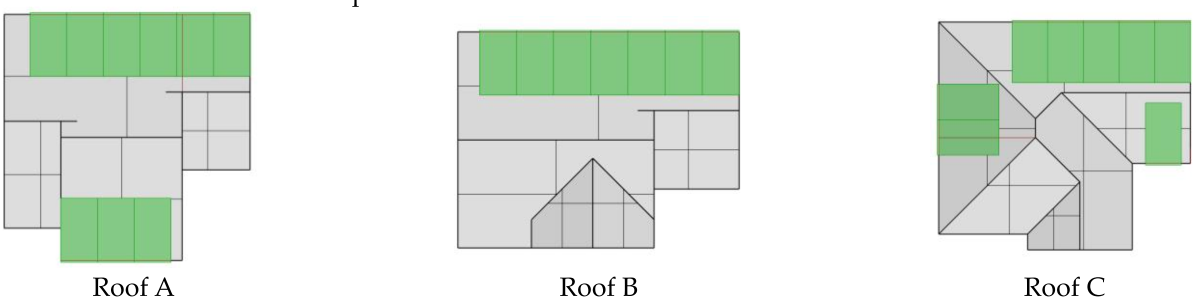

Figure 7. PV mounting capacity on each roof. There are 9 PV panels on roof A, 7 on roof B, and 8 on roof C.

4. Conclusions

Stacked gable roof is the most roof shape found in the design of detached housing in Gorontalo. Some roof shapes such as complex gable, and complex hip roof also observed in the city. They can be differentiated by the plane shape, directions, and the existence of self-shading. Research on the potential of PV installation on the 3 roofs resulting in stacked gable roof as the best roof shape to provide renewable energy to the housing with a condition, PV panels should not be mounted on the planes which shaded by the other roof parts.

Complex hip roof has planes facing 4 directions. There is no self-shading effect in the roof and all of the planes are suit for PV installation. Nevertheless, the presence of trapezoid and irregular planes poses a hindrance for the installation of bigger PV panels size and limit larger energy production

Author Contributions: Conceptualization, Methodology A.G.D.; Formal Analysis A.G.D. and N.P.; Writing—original draft, A.G.D. and R.; Visualization, Writing—review & editing, N.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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