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Optimizing Contoured Land for Residential Development

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A R T I C L E I N F O

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A B S T R A C T

This study analyzes land processing efficiency on contoured terrain in Kedamean, Gresik, as a peri-urban housing development area. The research compares the conventional *cut and fill* method with an adaptive site design approach to optimize land use and reduce infrastructure costs. A descriptive quantitative method was applied, using topographic measurements, field observations, and contour map analysis conducted in 2024. Earthwork volumes were calculated using specialized software and compared across both approaches. Results show that adaptive site design reduces earthwork volumes by 38–42%, infrastructure costs by 20–25%, and erosion potential by 30%. These findings highlight adaptive site design as a practical and sustainable strategy for efficient housing development on contoured land in peri-urban areas

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INTRODUCTION

Rapid urbanization in Surabaya has driven the expansion of residential areas in peri-urban regions. The limited availability of flat land and rising land prices in the city center have made surrounding areas such as Kedamean, Gresik, a primary target for new housing development. According to BPS (2023), the population growth rate in Gresik Regency has reached 1.37% per year, increasing the demand for residential land in line with population growth. Nationally, housing demand in Indonesia remains high. The Ministry of Public Works and Housing (PUPR, 2022) recorded a housing backlog of 12.7 million units, with a primary focus on providing subsidized housing for low-income communities. Peri-urban areas offer more affordable land prices, making them a strategic solution. However, the contoured topography of these areas poses serious challenges during the construction process. Conventional land processing methods, such as *cut and fill*, are commonly used to flatten contours. However, this approach requires significant investment—up to 20–30% of total site infrastructure costs (Kusumawanto, 2018). Beyond cost, *cut and fill* also risks causing environmental problems, including erosion, sedimentation, and damage to natural drainage systems (Rahmawati et al., 2021). As an alternative, adaptive site design can reduce earthwork volumes by up to 40%, lower construction costs, and maintain environmental sustainability (Sutrisno & Martono, 2020). Previous studies have discussed peri-urban dynamics and land-use conflicts (Hudalah et al., 2016), but research focusing specifically on efficiency strategies for contoured land processing in housing development, particularly in Kedamean, remains limited. Therefore, this study contributes to knowledge enrichment by providing a quantitative analysis of land processing efficiency through a comparative approach between *cut and fill* and adaptive site design methods for housing development in Kedamean, Gresik.

THEORETICAL REVIEW

Topography and Infrastructure Cost Theory

Topography is one of the key factors influencing residential infrastructure development costs. Contoured land is characterized by variations in elevation and slope, measured in percentage (%). According to the FAO classification, slope is categorized as flat (0–3%), gentle (3–8%), moderately steep (8–15%), steep (15–30%), and very steep (>30%). The greater the slope, the higher the development cost due to increased earthwork and retaining structure requirements (Rahmawati et al., 2021).

Previous studies (Kusumawanto, 2018) show that on a 15–20% slope, the earthwork volume can increase by more than 1.5 times compared to slopes below 10%. This directly impacts the increase in residential infrastructure development costs.

H1: The steeper the land slope, the greater the earthwork volume and infrastructure development cost.

Adaptive Site Design Efficiency Theory

The adaptive site design approach aims to minimize intervention with the natural topography, thereby significantly reducing the earthwork volume (cut and fill). Adaptive strategies include stilt houses, terracing, and natural drainage utilization to minimize hydrological changes. Sutrisno & Martono (2020) recorded an average efficiency of 38–42% in reducing cut and fill volumes compared to conventional methods, along with a 20–25% reduction in infrastructure costs.

H2: The application of adaptive site design can significantly reduce cut and fill volume and construction costs compared to conventional methods.

Conceptual Framework

This study employs a quantitative approach, focusing on the relationship between land slope, land processing methods, and infrastructure development costs.

- **Independent variables:** Land slope, land processing method (cut and fill vs. adaptive).
- **Dependent variables:** Earthwork volume and construction cost.
- **Hypotheses:** H1 and H2 as stated above.

his framework illustrates how increasing land slope influences earthwork volume and how adaptive site design can serve as an efficiency strategy to reduce development costs.

METHODOLOGY

Research Type and Approach

This study employs a quantitative descriptive approach with a case study in Kedamean, Gresik. The quantitative approach was chosen because the research focuses on measuring earthwork volume, estimating costs, and comparing efficiency between the cut and fill method and adaptive site design.

Research Location

The research location is situated in the peri-urban residential area of Kedamean, Gresik Regency, East Java. This area was selected based on the following considerations:

1. It is experiencing significant new housing development.
2. It has contoured topographic characteristics with elevation variations ranging from 5 to 25 meters.
3. It is one of the target areas for subsidized housing development.

Data and Data Sources

1. Primary Data
    a. Field topographic survey results (slope, elevation, contour measurements).
    b. Documentation of the physical site conditions.
2. Secondary Data
    a. Contour maps (Google Earth).
    b. Literature related to earthwork cost and land processing methods.

RESEARCH RESULTS

Site Profile of the Housing Area

The development site is located on Jalan Raya Madureso, Mojowuku Village, Kedamean District, Gresik Regency. The site profile is presented as follows:

Table 1. Site profile

Profile	Description
Location	Jl. Madureso, kedamean - Gresik
Area	41909 m2
Contour level different	11.5%
Owner	PT. Unison Pratama Jaya
Development plan	Housing

Site Characteristics

The Kedamean area features contoured topography with an average slope of 11.5%. This condition requires careful land processing to avoid excessive construction costs.

Figure 1. Site Contour Map
Source: Google Earth, 2025

Efficiency of the Cut and Fill Method

The cut and fill method is a primary approach in contour land processing aimed at achieving a balance between cut (excavated) and fill (embanked) soil volumes. The main principle is to minimize the need to transport soil material in or out of the site, thereby reducing construction costs, work duration, and environmental impacts. In the context of a site with an average slope of 11.5%, this method plays a crucial role in maintaining efficiency and land stability.

Topographic analysis was conducted using Autodesk Civil 3D to map existing contour conditions. The modeling results showed an elevation difference of approximately 8 meters from the northern to the southern part of the site. The contour visualization clearly indicated slope distribution and potential areas for cut and fill activities.

Figure 2. Existing Contour

The average elevation difference between lots of approximately 0.5 meters served as the basis for designing a terraced system that applies the principle of local cut and fill. This approach allows soil from the upper zone to be reused directly as fill material in the lower zone, achieving balanced earthwork and minimizing transportation needs.

This method provides several technical advantages:

1. Reduced need for high retaining structures, as wall heights remain below one meter.
2. Maintained lot accessibility according to technical standards.
3. Drainage systems can follow natural contours, making them more efficient and environmentally friendly.

Thus, a well-balanced cut and fill method becomes key to achieving construction efficiency while preserving the natural site character.

Comparative Analysis Between Conventional Cut and Fill and Adaptive Contour Design

Topographic analysis results were compared using two main approaches:

1. Conventional cut and fill (flattening)
2. Adaptive contour design

This comparison aims to evaluate technical effectiveness, cost efficiency, and alignment with sustainability principles.

Conventional Cut and Fill

The conventional cut and fill method aims to create a relatively flat surface by cutting higher elevations and filling lower areas to achieve uniform site levels. This strategy is often applied in large-scale housing projects as it simplifies construction work and infrastructure planning.

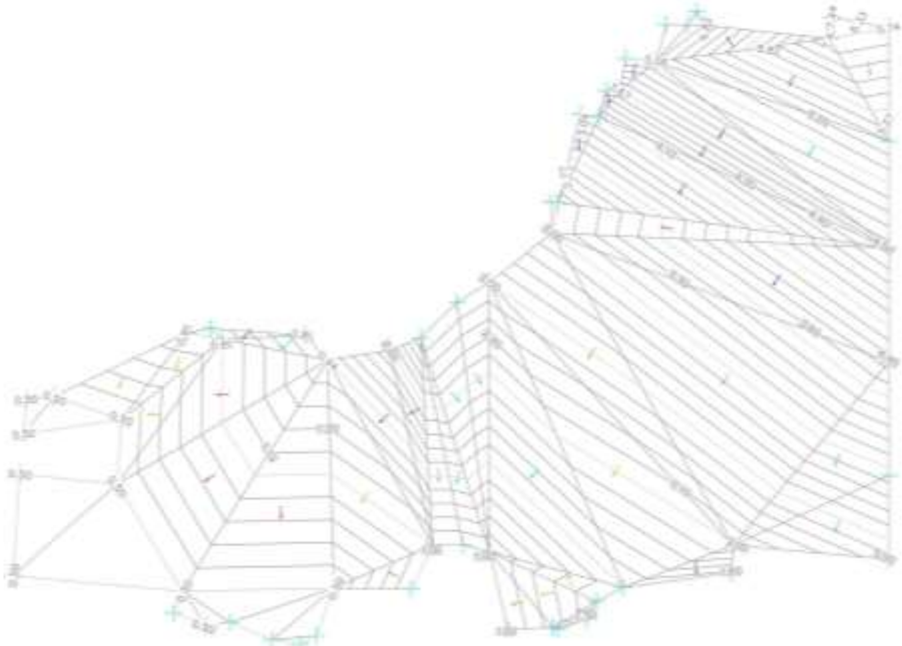

Figure 3. Contour with flattened methods

For the study site with an average slope of 11.5%, topographic simulation using Autodesk Civil 3D showed:

- Cut volume : **32,480.63 m³**
- Fill volume : **9,450.66 m³**
- Surplus : **23,029.97 m³**

This large volume imbalance indicates a significant amount of excess material that must be transported off-site, increasing transportation costs and environmental impacts.

Volume Summary

Name	Type	Cut Factor	Fill Factor	2d Area (sq.m)	Cut (Cu. M.)	Fill (Cu. M.)	Net (Cu. M.)
Surface tahap 1	full	1.000	1.000	41909.76	32480.63	9450.66	23029.97<Cut>

Totals

	2d Area (sq.m)	Cut (Cu. M.)	Fill (Cu. M.)	Net (Cu. M.)
Total	41909.76	32480.63	9450.66	23029.97<Cut>

* Value adjusted by cut or fill factor other than 1.0

Figure 4. Cut and fill report with flattened methods

The imbalance also highlights that flattening contour sites with moderate to steep slopes results in low earthwork efficiency. A larger cut volume implies more heavy machinery use, longer construction time, and higher costs. Moreover, drastic landform changes can reduce slope stability and increase erosion and sedimentation risks.

From an infrastructure perspective, this method generates sharp elevation differences requiring high retaining structures (>1 meter), which raises construction and maintenance costs. It also reduces soil infiltration capacity and increases surface runoff, necessitating more complex artificial drainage.

Visually, the conventional method eliminates natural landform characteristics, resulting in uniform landscapes. While practical for construction, the high costs and ecological impacts make this approach less efficient for sloped sites.

Adaptive Contour Design

The adaptive contour design approach integrates site planning with existing topography, minimizing landform alteration. This method aligns with the minimum earthwork principle, which aims to balance cut and fill volumes to reduce soil import/export needs.

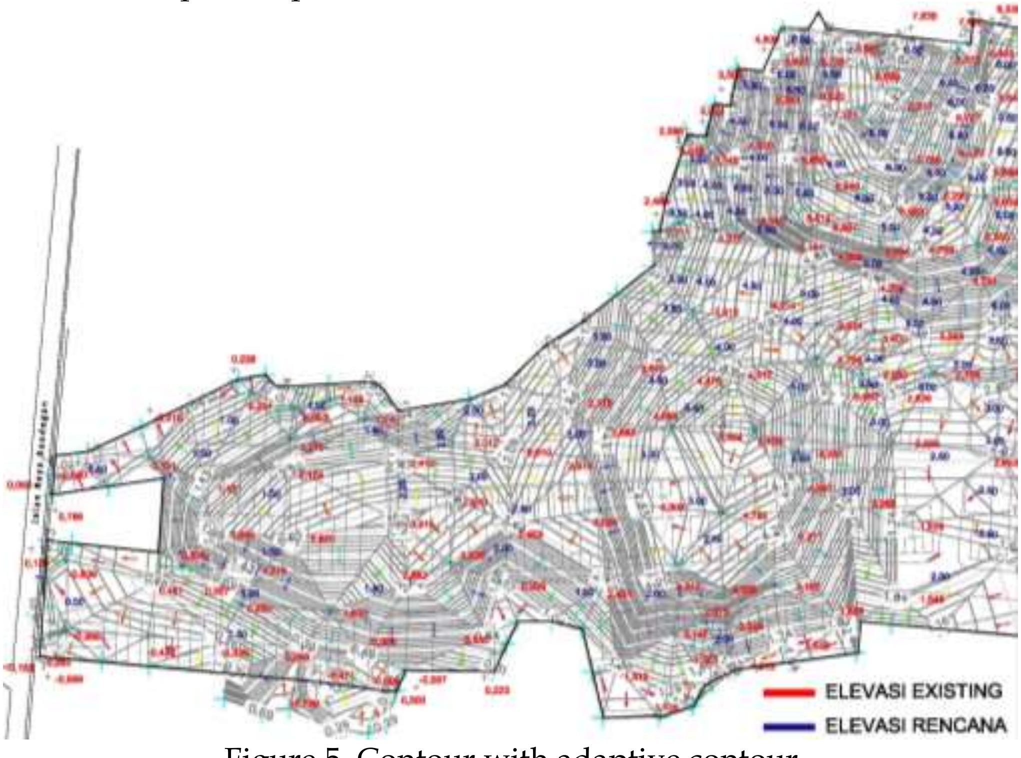

Figure 5. Contour with adaptive contour

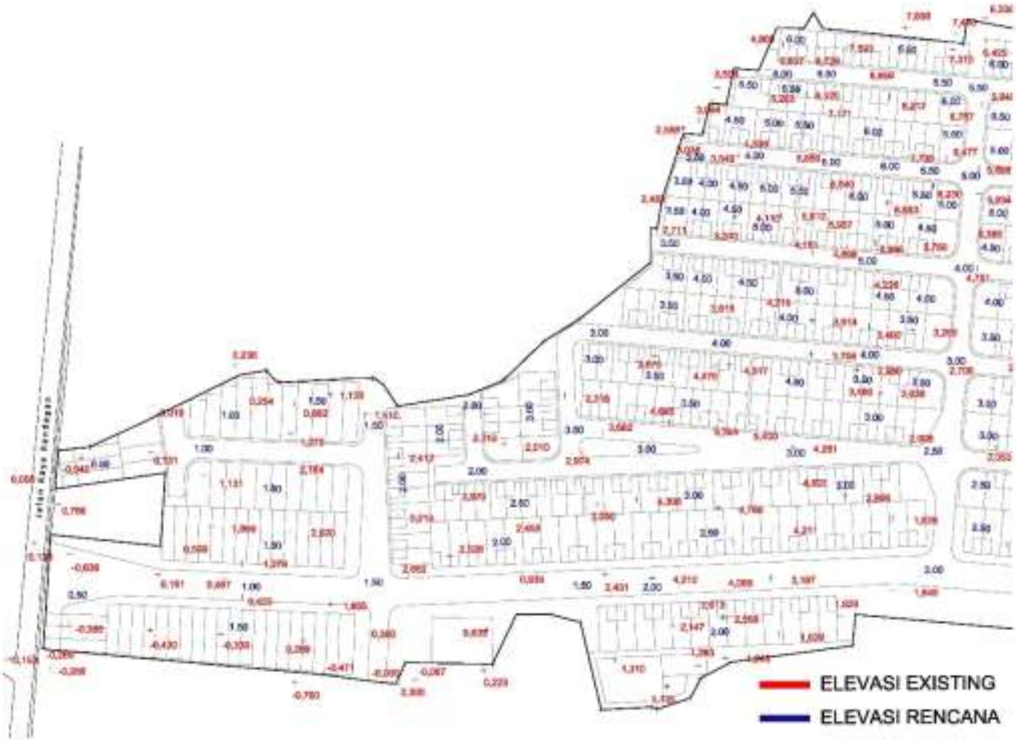

Figure 6. Contour with adaptive contour design approach integrates site planning

Using Autodesk Civil 3D 3D modeling integrated with a contour-responsive site plan, the simulation results showed:

- Cut volume : **21,223.13 m³**
- Fill volume : **20,686.63 m³**
- Surplus : **536.5 m³**

This near-perfect balance shows the efficiency of adaptive methods in reusing excavated material within the site.

Volume Summary

Name	Type	Cut Factor	Fill Factor	2d Area (sq.m)	Cut (Cu. M.)	Fill (Cu. M.)	Net (Cu. M.)
Surface tahap 1	full	1.000	1.000	41909.76	21223.13	20686.63	536.50<Cut>

Totals

	2d Area (sq.m)	Cut (Cu. M.)	Fill (Cu. M.)	Net (Cu. M.)
Total	41909.76	21223.13	20686.63	536.50<Cut>

* Value adjusted by cut or fill factor other than 1.0

Figure 7. Cut and fill report with adaptive contour

The adaptive method was implemented in three key steps:

1. Zoning by elevation – steeper slopes are allocated for green or conservation areas, while gentler slopes are used for housing.
2. Road and lot layout – designed along contour lines, with gradients of 8–10% to meet comfort and safety standards.
3. Natural drainage integration – directing water flow along contour valleys toward micro-infiltration points in low-lying areas.

This strategy not only maintains balanced earthwork but also produces a site plan that is ecologically efficient and context-sensitive. The terraced lot pattern allows direct reuse of excavated soil, minimizes the need for retaining walls, and stabilizes slopes. Following natural contours for drainage improves water infiltration and reduces surface runoff.

In terms of sustainability, this approach reflects the "Respect for Site" principle in green architecture, emphasizing minimal human intervention and preservation of natural site character. With balanced earthwork and natural stormwater management, adaptive contour design supports efficient, stable, and resilient housing development.

Comparative Efficiency Analysis

The comparison between conventional cut and fill and adaptive contour methods assessed earthwork efficiency, soil volume balance, and technical and ecological impacts based on Autodesk Civil 3D modeling.

Table 2. Comparison between the cut and fill leveling method and the contour adaptation method

Land Processing Method	Cut Volume **(m3)**	Fill Volume **(m3)**	Difference	Soil Balance	Technical Implications
Conventional Cut & Fill	32.480,63	9.450,66	23.029,97	Imbalanced (large surplus)	High cost, requires external hauling, high erosion risk
Adaptive Contour Design	21.223,13	20.686,63	536,50	Nearly balanced	Efficient, minimal hauling, stable slope

The conventional method creates a significant imbalance, with a surplus of 23,029.97 m³, increasing transportation costs and construction time. It also requires more retaining walls and poses higher erosion risks.

In contrast, the adaptive method shows much better efficiency, with only 536.5 m³ difference between cut and fill volumes, meaning most excavated soil can be reused on-site. This reduces heavy machinery use, soil transport, and construction costs. Ecologically, the adaptive approach preserves the natural site character, improves water infiltration, and minimizes runoff.

Table 2. Qualitative Comparison of Land Processing Methods

Analysis Aspect	Conventional Cut & Fill	Adaptive Contour Design
Earthwork efficiency	Low, large difference between cut & fill	High, near-perfect balance
Construction cost	High, due to transport and retaining walls	Lower, soil reused locally
Site stability	Prone to erosion and landslides	Stable, follows natural slope
Drainage system	Artificial, requires large channels	Natural, follows contour valleys
Landscape quality	Uniform, loses natural identity	Varied and contextual to the terrain
Environmental sustainability	Low, due to high land intervention	High, aligns with "Respect for Site" principles

DISCUSSION

The findings of this study reveal that the choice of land processing methods significantly affects the technical, economic, and environmental outcomes of housing development on contoured land. The conventional cut and fill approach, although widely practiced, tends to increase earthwork volume, elevate construction costs, and cause environmental degradation through erosion and disruption of natural drainage systems. In contrast, the adaptive contour design method demonstrates a more site-sensitive strategy that aligns building layouts with the natural topography, thereby minimizing earthwork, preserving ecological functions, and improving long-term resilience. This approach supports the principles of sustainable land development and green architecture by reducing environmental impact while enhancing cost efficiency (Sutrisno & Martono, 2020; Rahmawati et al., 2021). In peri-urban areas such as Kedamean, adaptive site design provides a practical and strategic solution to topographic constraints, contributing to more sustainable and livable residential environments.

CONCLUSIONS AND RECOMMENDATIONS

This study highlights the crucial role of land processing methods in determining the efficiency, stability, and sustainability of housing development on contoured sites. The comparative analysis between the conventional cut and fill leveling method and the adaptive contour method shows that the adaptive approach achieves a more balanced earthwork, reduces construction costs, and minimizes environmental impacts. By aligning the site plan with natural topography, this method preserves ecological functions, improves drainage performance, and enhances site resilience. Based on these findings, developers and planners are encouraged to prioritize adaptive contour-based site planning to achieve both technical efficiency and ecological sustainability. Regulatory bodies should also integrate adaptive land development principles into planning guidelines for residential projects on contoured land. Furthermore, future research is recommended to combine adaptive contour methods with green infrastructure and climate-resilient housing strategies to strengthen long-term sustainability. Collaboration between planners, engineers, and environmental experts is essential to ensure that housing development respects the natural site characteristics while fulfilling social and economic needs.

FURTHER STUDY

Every research has its limitations, and this study is no exception. The analysis focused primarily on earthwork volume efficiency and technical site planning, without incorporating long-term performance aspects such as maintenance costs, environmental impact over time, or community livability. Future studies are recommended to expand the scope by integrating hydrological simulations, soil stability assessments, and climate resilience strategies to provide a more comprehensive understanding of the site's sustainability. Moreover, applying adaptive contour methods in different topographical and regional contexts could offer valuable insights into their broader applicability. Collaboration with multidisciplinary experts—such as environmental engineers, urban planners, and landscape architects—will also strengthen future investigations and support more holistic residential development strategies.

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