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SMART–C3: An Integrated TPS-3R Cluster Model for Circular Economy and Zero-Waste Management in Bali, Indonesia

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A B S T R A C T

The research evaluates the operational performance, challenges, and developmental potential of the TPS-3R waste management system in Tangkas Village, Bali, and introduces the SMART–C³ Model as a solution to improve sustainability and operational efficiency. Utilizing a qualitative descriptive methodology, the study gathered data through interviews with key stakeholders, including village officials, TPS-3R managers, sanitation workers, and community members, as well as field observations of waste management activities and document analysis. The results indicate that while the facility handles approximately 38–40 tons of waste monthly, its success is limited by inconsistent household segregation, high residual waste generation, infrastructure constraints, workforce shortages, and weak institutional enforcement. Public participation remains moderate, particularly regarding segregation and recycling efforts. Additionally, the study identifies that although the Organic Waste Recycling Center provides valuable secondary processing, it is not effectively integrated into the overall system. Differing from conventional TPS-3R practices, this study proposes the SMART–C³ Model, which incorporates smart monitoring, cluster-based processing, segregation-based collection, and community-focused behavioral change within a unified circular-economy framework. This scalable, community-driven approach enhances stakeholder participation and resource recovery while reducing reliance on landfills, offering a robust strategy for reaching zero-waste targets in rural and semi-urban regions.

Contribution to Sustainable Development Goals (SDGs):
SDG 11: Sustainable Cities and Communities
SDG 12: Responsible Consumption and Production
SDG 13: Climate Action

1. INTRODUCTION

1.1. Research Background

Waste management has become a critical environmental and socio-economic challenge, particularly in rapidly urbanizing regions such as Indonesia. In Tangkas Village, Bali, the TPS-3R (Reduce, Reuse, Recycle) system processes approximately 38–40 tonnes of waste per month; however, its effectiveness remains constrained by low household waste segregation, high residual waste generation, limited infrastructure, workforce shortages, and weak institutional enforcement [1], [2]. These challenges reduce resource recovery, increase dependence on landfills, and hinder the achievement of sustainable waste management goals.

The challenges in Tangkas Village including low community participation, limited operational capacity, and weak stakeholder coordination—are common in developing regions. These issues demonstrate that infrastructure development alone is insufficient; effective waste management requires integrating community behavior, operational efficiency, and institutional support. Addressing inconsistent waste segregation and insufficient source-based recovery is essential to mitigating the growing volume of household waste [3], [4].

Transitioning from linear waste disposal to circular economy principles—emphasizing reduction, reuse, recycling, and resource recovery offers a sustainable solution to environmental and economic challenges. Supplementing these strategies with smart technologies can further enhance transparency and operational decision-making. Despite this potential, current research often isolates operational performance from community engagement. The SMART–C³ model addresses this fragmentation by integrating technological innovation, cluster-based management, and behavioral transformation into a unified framework that bridges the gap between policy mandates and field-level operational realities [5], [6].

Global and regional studies consistently emphasize the importance of integrated waste management systems that combine technology, governance, and community engagement [7]. Research in Indonesia shows that circular economy implementation can improve resource utilization and environmental quality [7], while successful TPS-3R systems require strong institutional support and active community participation. Similar findings across Asia demonstrate that integrated approaches contribute significantly to waste reduction and sustainability outcomes [2].

In response to these challenges and research gaps, this study proposes the Smart Integrated TPS-3R Cluster Model (SMART–C³), which combines smart monitoring technologies, cluster-based waste processing, community behavioral transformation, and circular economy principles within a single framework. The model aims to improve resource recovery, strengthen stakeholder participation, enhance operational efficiency, and reduce landfill dependency, providing a scalable pathway toward sustainable and zero-waste communities.

1.2. Literature Review

Recent literature highlights community-based waste management, particularly TPS-3R facilities in Indonesia, as a strategy to reduce landfill dependency through local recycling and composting. These systems promote decentralized waste recovery. However, they frequently face hurdles such as mixed-waste disposal, low participation, poor infrastructure, and rising waste volumes. While TPS-3R facilities support waste reduction, many underperform due to inconsistent segregation and operational constraints [8]. Similar challenges across other developing nations suggest that decentralized systems often struggle to achieve long-term efficiency and sustainability [9].

Literature consistently identifies waste management as a multidimensional challenge that exceeds technical solutions alone. Research on Community-Based Waste Management highlights that active participation, environmental awareness, and social norms significantly influence segregation behavior [10], [11]. From an operational standpoint, insufficient infrastructure, limited technology, and workforce shortages drive inefficiencies and high residual waste [12]. Furthermore, Institutional Theory indicates that weak governance, fragmented stakeholder coordination, and poor policy enforcement undermine overall sustainability [13]. These barriers are observed similarly across other Asian contexts, including Vietnam and China [14], [15].

Recent literature advocates for Circular Economy Theory to transform waste into a valuable resource. These approaches recycling, composting, and resource recovery mitigate environmental impacts while generating economic value [16]. In Indonesia, these principles have successfully improved composting efficiency and organic waste valorization [17]. Furthermore, technological innovations, including Internet of Things monitoring and data-driven systems, have enhanced operational efficiency, transparency, and decision-making in waste management [18], [19].

Synthesizing these studies confirms that sustainable waste management requires an integrated framework combining community participation, technological innovation, resource recovery, and institutional support [9]. While research suggests that cluster-based and network-oriented approaches improve processing efficiency and optimize resource utilization, a critical gap remains. Existing studies often examine operational performance, community engagement, and circular economy principles as isolated components rather than integrated systems. There is limited research synthesizing smart monitoring, behavioral transformation, and cluster-based management within a unified TPS-3R framework, leaving the collective impact of these dimensions on waste recovery and landfill reduction insufficiently understood.

Table 1. Study proposes the smart integrated TPS-3R cluster model (SMART–C³)

Study Focus	Key Findings	Limitation
TPS-3R Operational Performance	TPS-3R reduces waste sent to landfills and supports recycling.	Focuses primarily on operational indicators; limited social analysis.
Community Participation in Waste Management	Household awareness and participation influence segregation success.	Limited integration with technological and institutional factors.
Circular Economy Applications	Resource recovery and waste valorization improve sustainability.	Often lacks implementation mechanisms at the community level.
Smart Waste Management Technologies	IoT and monitoring systems improve efficiency and transparency.	Technology-focused; limited behavioral and governance considerations.
Cluster-Based Waste Management Approaches	Improve logistics, processing efficiency, and resource sharing.	Rarely integrated with TPS-3R and circular economy systems.
Present Study (SMART–C³ Model)	Integrates smart monitoring, cluster-based processing, behavioral transformation, institutional support, and circular economy principles.	Addresses identified gaps through a unified framework.

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To address this gap, this study proposes the Smart Integrated TPS-3R Cluster Model (Table 1), which unifies decentralized collection, cluster-based processing, smart monitoring, circular economy practices, and community behavioral transformation. By integrating these elements, the model aims to optimize resource recovery and operational efficiency, foster stakeholder participation, and provide a scalable path toward zero-waste communities. This approach offers a holistic framework that addresses the intersecting socio-cultural, technical, and economic challenges typical of rapidly urbanizing emerging economies [20].

1.3. Theoretical Framework

This study is anchored in four complementary theoretical perspectives that collectively explain the development and implementation of the SMART–C³ (Smart Monitoring, Adaptive Resource Management, and Transformative Community Clusters) Model.

First, Circular Economy Theory provides the overarching sustainability framework. It promotes the reduction of waste and the recovery of resources through reuse, recycling, composting, and valorisation processes, thereby minimising landfill dependency and creating economic value from waste streams. Within the SMART–C³ Model, circular economy principles guide the design of waste processing, resource recovery, compost production, and recycling activities. This framework transitions waste management from a linear disposal model toward a restorative system, emphasizing net environmental output over final discharge [21].

Second, the Community-Based Waste Management (CBWM) framework emphasizes the importance of decentralized governance and active community participation in waste management systems. Previous studies demonstrate that community ownership and local engagement improve accountability, operational effectiveness, and long-term sustainability [9]. In this study, CBWM is reflected in the cluster-based management approach and the W4C (Ways for Change) strategy, which encourages household participation and collective responsibility for waste segregation and resource recovery.

Third, the study incorporates the Theory of Planned Behavior (TPB), which explains how attitudes, subjective norms, and perceived behavioral control influence individual behavior. The TPB provides the behavioral foundation of the SMART–C³ Model by supporting educational campaigns, incentive–penalty mechanisms, and awareness programs designed to improve household waste segregation and participation in recycling activities. Finally, the Social Practice Theory offers a lens to analyze how everyday routines and habits intersect with the introduced technological infrastructure to solidify long-term waste management practices [22]. By examining the material conditions and social rituals that dictate waste disposal, this perspective ensures that the model's systemic changes are embedded in daily life rather than existing merely as external mandates [23].

Finally, Institutional Theory emphasizes the role of governance structures, policies, regulations, and stakeholder coordination in shaping organizational behavior and system performance [24]. Strong institutional support ensures compliance, accountability, and effective coordination among local governments, TPS-3R operators, community groups, and other stakeholders. In this study, institutional mechanisms include policy enforcement, stakeholder collaboration, and the application of local regulations (awig-awig) to strengthen the implementation of waste management.

These theories form the conceptual foundation of the SMART–C³ Model. Circular Economy Theory defines sustainability goals through resource recovery and waste reduction [25]. Community-Based Waste Management and the Theory of Planned Behavior explain how community engagement and behavioral shifts drive these outcomes [26], while Institutional Theory provides the governance mechanisms to enforce regulations and coordinate stakeholders [27]. Together, they create a comprehensive framework that integrates behavioral change, community participation, technology, and institutional support to enhance waste management performance and achieve zero-waste objectives.

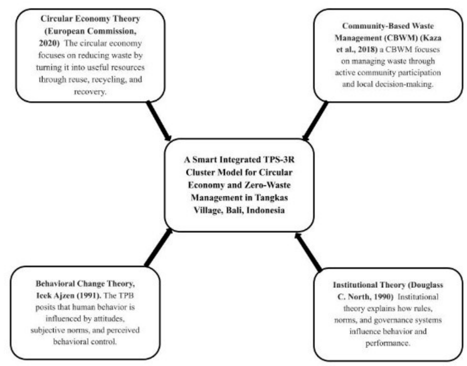

Fig. 1. Theoretical framework.

Figure 1. illustrates the relationship among these theoretical foundations and demonstrates how each theory contributes to the SMART–C³ Model. Circular Economy Theory serves as the sustainability goal; TPB drives behavioral transformation; CBWM strengthens community participation and decentralized management; and Institutional Theory provides governance and enforcement mechanisms. These interconnected components collectively support smart monitoring, cluster-based processing, resource recovery, and sustainable waste management outcomes.

1.4. Research Objective

This study aimed to develop a smart, integrated TPS-3R cluster model to strengthen community-based waste management in Tangkas Village, Bali, by applying circular economy principles, smart monitoring, and institutional mechanisms toward zero-waste outcomes. It specifically sought to evaluate current TPS-3R practices and performance in terms of household waste segregation, processing activities, and community participation; to analyze behavioral, operational, and institutional challenges affecting system effectiveness; to examine the role of TPS-3R units and the Organic Waste Recycling Center (Organic Fertilizer Factory) in supporting resource recovery and reducing landfill use; and to propose a smart integrated TPS-3R cluster model that enhances community-based management in Tangkas Village, Bali, Indonesia.

2. MATERIALS AND METHODS

This study employed a qualitative descriptive research design to examine the operational, behavioral, and institutional dynamics of the TPS-3R waste management system in Tangkas Village, Bali. This approach provided an in-depth understanding of stakeholder experiences, waste management practices, and contextual challenges within a community-based waste management setting.

2.1. Research Participants and Sampling

Participants were selected using purposive sampling to include 25 individuals with direct experience of the TPS-3R system, including representatives from the Darma Winangun Community Self-Help Group, facility managers, waste workers, village officials, and community members. Inclusion required active involvement in or knowledge of waste management in Tangkas Village, ensuring rich, multi-perspective data. Semi-structured interviews and participatory observations were integrated to triangulate stakeholder dynamics and evaluate operational efficiency [28], [29]. The assessment also addressed common barriers, such as the persistence of unsegregated waste at the source and limited operational funding.

2.2. Research Instruments and Data Collection

Data were collected using two primary instruments: a semi-structured interview guide and an observation checklist. The semi-structured interview guide explored participants' experiences regarding waste segregation, operational challenges, community participation, institutional support, and improvement opportunities for the TPS-3R system. An observation checklist systematically evaluated the facility's infrastructure, sorting equipment, and workflow. Furthermore, evaluating site-specific logistics helped identify bottlenecks in the waste value chain, complementing the qualitative interview insights [30]. To ensure credibility, the research employed source triangulation by cross-referencing interview data, field observations, and policy documentation.

Field observations were conducted through ocular site visits at the TPS-3R facility, waste collection points, and surrounding service areas. An observation checklist was used to systematically assess waste segregation practices, collection procedures, processing activities, facility conditions, equipment utilization, workforce activities, and community participation. These observations enabled the researcher to document actual practices and identify gaps between intended and implemented waste management processes.

2.3. Data Analysis Procedure

Data were analyzed using thematic analysis. Interview transcripts and field observation notes were reviewed and organized to identify recurring patterns and significant issues. The analysis followed four stages: (1) data familiarization through repeated reading of interview transcripts and observation records; (2) open coding to identify key concepts and issues; (3) categorization of codes into broader themes related to behavioral, operational, and institutional dimensions; and (4) interpretation of themes to explain system performance and inform the development of the SMART–C³ Model.

2.4. Validity and Trustworthiness

To enhance the credibility and trustworthiness of the findings, methodological triangulation was employed by comparing interview responses with field observation results. Data source triangulation was also conducted by gathering information from different stakeholder groups, including TPS-3R managers, workers, village officials, and community members. Member checking was undertaken when necessary to verify the accuracy of participants' responses and interpretations.

2.5. Ethical Considerations

The study adhered to ethical research principles. Participants were informed of the purpose of the study and their voluntary participation prior to data collection. Informed consent was obtained from all participants, and confidentiality was maintained by anonymizing personal identifiers in interview transcripts and research reports. All collected information was used solely for academic purposes.

3. RESULT AND DISCUSSION

3.1. Results

The findings reveal that the effectiveness of the TPS-3R system in Tangkas Village is constrained by interconnected behavioral, operational, and institutional factors rather than by infrastructure limitations alone. Although the facility processes approximately 38–40 tons of waste monthly, low household waste segregation, limited participation, and governance challenges reduce overall system efficiency and resource recovery.

Behavioral compliance remains low because waste segregation is not yet a social norm. Following the Theory of Planned Behavior, households participate more when they perceive clear benefits, social expectations, and institutional support. In Tangkas Village, however, the convenience of disposing of mixed waste outweighs segregation efforts due to a lack of consistent incentives, penalties, and monitoring. Similar to other Indonesian TPS-3R systems, where participation depends on continuous reinforcement, Tangkas Village currently lacks the waste banks and incentive schemes found in more successful models, which weakens behavioral compliance.

Institutional challenges further explain the persistently low participation. Despite existing organizational structures, governance remains weak. Institutional Theory suggests that formal rules only influence behavior when supported by enforcement, accountability, and stakeholder coordination [31]. In Tangkas Village, regulations and customary laws are underutilized, failing to drive compliance. This contrasts with successful programs in other parts of Bali and Indonesia, where community leadership actively enforces local rules. Consequently, the institutional presence in Tangkas Village remains more structural than operational.

Bali's cultural context, characterized by strong social networks and customary governance, offers significant potential for waste management. Despite a history of supporting environmental initiatives, these social structures remain underutilized. Leveraging traditional institutions such as banjar organizations and customary leaders could strengthen social norms and collective responsibility for waste segregation, leading to improved compliance and community ownership.

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Similarly, operational challenges are linked to upstream behavioral and institutional issues. The need for extensive secondary sorting demonstrates that inefficiencies originate not only within the facility but also at the household level. As a result, workers spend considerable time separating mixed waste rather than focusing on resource recovery activities. This finding is consistent with studies of TPS-3R facilities in Indonesia, where poor source segregation frequently reduces processing efficiency and increases operational costs [13]. The high proportion of organic waste, however, presents significant opportunities for composting, organic fertilizer production, and other circular economy initiatives if supported by stronger segregation practices and processing capacity.

Comparatively, international circular economy models emphasise the integration of behavioural, technological, and institutional components. Unlike Tangkas Village's manual, informal TPS-3R system, countries such as Japan, Singapore, South Korea, and parts of Europe achieve high efficiency through strict regulations, strong social norms, and digital monitoring systems [32], [33]. The proposed SMART–C³ Model bridges this gap by integrating smart monitoring, cluster-based processing, behavioral transformation, and institutional strengthening into a unified framework.

The Organic Waste Recycling Center enhances integrated waste governance by functioning as a secondary processing hub. Unlike conventional TPS-3R systems primarily focused on collection and sorting, this center transforms waste into value-added products such as compost and liquid fertilizer. This network-based strategy reflects circular economy models in various Asian countries that connect decentralized collection to centralized processing facilities [34]. However, its effectiveness depends on input quality and stakeholder coordination. Therefore, strengthening linkages between households, TPS-3R facilities, and recycling centers is essential to maximize resource recovery and reduce landfill dependency.

Overall, the findings demonstrate that sustainable waste management requires more than operational improvements. Effective waste governance depends on the interaction of behavioral compliance, institutional capacity, cultural support systems, and technological innovation. The SMART–C³ Model responds to these challenges by integrating community participation, smart monitoring, cluster-based management, and circular economy principles into a comprehensive framework for achieving long-term waste sustainability and zero-waste outcomes.

3.2. Discussion

Based on the findings, this study proposes the SMART–C³ Model (Smart Monitoring, Adaptive Resource Management, and Transformative Community Clusters) as an integrated framework for addressing the behavioral, operational, and institutional challenges affecting the TPS-3R system in Tangkas Village. The model combines five SMART components—Segregation-Based Collection, Smart Monitoring, Adaptive Cluster Management, Resource Recovery, and Technology Integration with three supporting C³ pillars: Community Participation (W4C Approach), Circular Economy Practices, and Cluster-Based Processing Systems.

The SMART–C³ Model differs from conventional TPS-3R systems, which generally focus only on facility-based processing. This model integrates behavioral strategies, smart monitoring, cluster-based governance, and circular economy principles into a unified framework. Moreover, it connects households, TPS-3R units, secondary processing facilities, government, and the community to create a closed-loop waste management system. By combining technological innovation with social dynamics, this framework positions community participation as the foundation for sustainable systemic change [35].

The model addresses key study findings through five integrated components. Segregation-Based Collection improves input quality via source separation, while Smart Monitoring enhances transparency and efficiency through real-time tracking. Adaptive Cluster Management optimises logistics by organising manageable service areas. Resource Recovery converts waste into compost, recyclables, and fertilizers, supported by Technology Integration for data-driven planning. Finally, the C³ pillars strengthen the framework by fostering community engagement, formalizing local waste regulations, and optimizing institutional capacity [36], [37].

The C³ pillars strengthen the sustainability of the model. Community Participation, operationalized through the Ways for Change approach, promotes behavioral transformation through education, incentives, community engagement, and social accountability. Circular Economy Practices ensure that waste is continuously recovered, reused, recycled, and valorized [38]. Cluster-Based Processing Systems improve efficiency by connecting decentralized collection units with centralized processing facilities and secondary recycling centers [39].

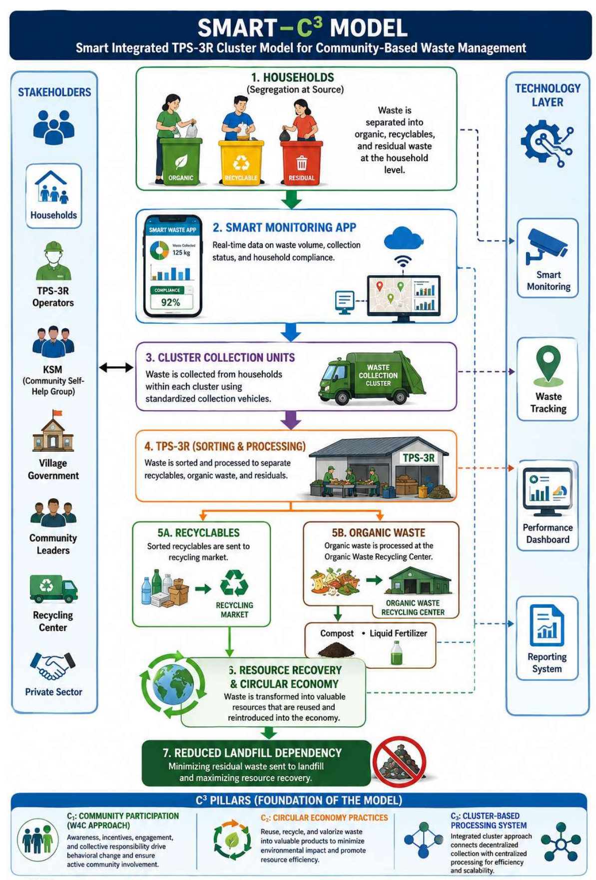

Fig. 2. SMART–C³ model.

Figure 2. SMART–C³ Model: An Integrated Framework Showing Waste Flow, Stakeholder Interactions, Smart Monitoring Technologies, Resource Recovery Processes, and Circular Economy Pathways for Community-Based Waste Management in Tangkas Village, Bali.

The SMART-C³ Model was validated through consultations with TPS-3R managers, KSM representatives, waste workers, village officials, and community members. Participants agreed that integrating smart monitoring, cluster-based management, and community participation addresses existing system limitations. Stakeholders also identified the link to the Organic Waste Recycling Center as a practical way to improve resource recovery and reduce waste. Furthermore, IoT sensors and data analytics offer the infrastructure needed to optimize collection routes and monitor bin levels, reducing costs and increasing service accountability [40]. A feasibility assessment suggests that the model can be implemented gradually, as Tangkas Village already has partial foundations in place, such as household segregation, community education, cluster-based collection, and secondary-processing partnerships. The proposed model leverages these existing elements rather than requiring a completely new system. While a full-scale pilot was beyond this study's scope, a conceptual simulation indicates that improved segregation, stronger stakeholder coordination, and better processing integration could substantially increase resource recovery and reduce residual waste.

Figure 2 illustrates the operational flow of the SMART–C³ Model. The figure demonstrates how waste moves from households through source segregation, cluster-based collection systems, TPS-3R processing units, and secondary recycling facilities before being transformed into valuable outputs such as compost, recyclables, liquid fertilizers, and other bio-based products. It also outlines stakeholder interactions among households, community organizations, TPS-3R operators, village governments, recycling centers, and private-sector partners. Smart monitoring technologies are embedded throughout the system to facilitate waste tracking, performance monitoring, reporting, and data-driven decision-making. This integrated flow highlights the model's ability to connect technological, behavioral, operational, and institutional dimensions within a unified circular economy framework.

Overall, the SMART–C³ Model demonstrates that sustainable waste management requires more than infrastructure and waste-processing facilities. Effective waste governance depends on the integration of community participation, technological innovation, institutional coordination, and circular economy principles. By linking upstream and downstream waste management processes, the model provides a scalable and context-specific framework for achieving zero-waste outcomes in rural and semi-urban communities.

4. CONCLUSION

Despite its progress in local waste processing and resource recovery, the TPS-3R framework in Tangkas Village is hindered by behavioral, operational, and institutional challenges, notably inconsistent waste segregation, insufficient infrastructure, and weak stakeholder coordination.

While TPS-3R units and the Organic Waste Recycling Center are vital for circular economy initiatives, their impact is often limited by fragmented integration and inconsistent community participation. This highlights the need for a holistic framework that integrates community behavior, operations, technology, and institutional support.

Theoretically, this study advances the field by introducing the SMART–C³ Model, which enhances the TPS-3R framework through the integration of smart monitoring, cluster-based management, behavioral change strategies, and circular economy principles. From a practical standpoint, the model cultivates synergy among households, TPS-3R facilities, secondary processing centers, and local institutions, effectively driving operational efficiency.

In terms of policy, there is a necessity for enhanced waste segregation mandates, consistent community outreach, incentive-based penalty structures, and digital monitoring capabilities. Due to the study’s qualitative design and limited scope, subsequent research ought to focus on quantitatively validating the SMART–C³ Model, performing comparative regional studies, and examining the implementation of cutting-edge digital tools, such as AI-powered analytics and IoT, to maximize waste management effectiveness.

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