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Research article

Integrated Computational Fluid Dynamics and Space Syntax simulation of evacuation efficiency and fire spread in informal local markets

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Abstract: Local markets make a significant contribution to urban livelihood and economic development, especially in low-income areas. This research evaluates the contribution of the spatial design of a local market to reducing fire risk in the urban areas of low economies. Fire calamities in regional local markets have caused extensive economic losses and property damage, resulting from ineffective spatial organisation, inadequate fire safety measures, and combustible building materials. Supported by interviews, field observations, and QGIS mapping, the study has integrated Space Syntax analysis and Computational Fluid Dynamics (CFD) simulation to quantify both human evacuation performance and environmental fire spread within the same context. Though both CFD modelling and Space Syntax have long-established applications in formal building design, the study denotes the integrated application of both techniques to assess fire safety in informal market contexts. The study revealed low visual integration, critical vulnerabilities, narrow aisles, and a lack of evacuation routes as significant problems. The findings have shown difficulties in firefighting equipment and combustible building materials present for rapid fire spread. The evacuation simulations through Pathfinder and CFD have identified bottlenecks in most of the high-density areas, causing delays in escape. The research proposes a spatial design intervention in terms of the use of fire-resistant materials, zoning of highly combustible commodities, evacuation routes optimised, and signage and awareness provided to the occupants. The results highlight essential policy implementation via the Fire and Rescue Force Act and practical redesigning of local market structure to promote safety. It is about guiding fire risk reduction policy measures to provide solutions to policymakers and urban planners to protect economic stability and livelihoods in low economies.

Keywords: fire outbreak risks, local market, spatial design, vulnerability factors, fire risk mitigation

1. Introduction

In the context of the modern world, the struggle to attain basic needs for oneself and one's family has prompted a massive increase in self-employment, mostly in the small business sector. Some of these livelihood-based businesses involve the sale of different products like foodstuffs, clothing, electronics, and household items. They offer more services, including financial, which are very important to most individuals in developing nations (Fields, 2019). In Africa, specifically Tanzania, informal local markets have emerged as key economic activity centres (Rambau, 2019). The markets offer livelihoods to millions of individuals and are key to supporting national economies, with their function being key in income generation and in supporting small-scale entrepreneurial ventures (Hilary et al., 2020). Although they are economically relevant, these markets are very susceptible to fire accidents, which can cause catastrophic effects not only on entrepreneurs but also on their families and the surrounding communities.

These fire incidents are a significant problem worldwide. The World Fire Report 2020 approximates that fire deaths worldwide average 280,000 annually, with developing nations experiencing the largest number of such tragedies. Fires in markets have become more common in Africa, resulting in the loss of property and lives, which in turn impact local economies. In Tanzania, the Tanzania Fire and Rescue Force (URT, 2021) documented a total of 3,456 fire incidents for the year 2020 that impacted different sectors such as residential areas, commercial areas, and markets. Surprisingly, more than 10% of such incidents took place in informal local markets, which indicates the susceptibility of these economic centres. Tanzania's vulnerability to fire disasters can be seen in its ranking as one of the top 25 countries in the world as far as fire-related deaths are concerned, recording a mean of 2,808 deaths annually (Mboma, 2022).

In Tanzania, private and public markets are important constituents of the economy. Yet, there exists a stark difference in the level of fire preparedness between these two market categories. Private markets tend to be better equipped with resources, expertise, and facilities to respond to fire outbreaks than public markets. Public markets have tremendous problems, such as having no adequate fire prevention measures, no adequate fire-

fighting facilities, and no adequate fire safety awareness. Research carried out by Mboma (2022) shows that private markets have 80% knowledge of fire safety, but public markets have only approximately 40%. This knowledge and resource gap exposes a significant percentage of the population to risk, especially in informal markets where most of the small businesses are located.

In informal markets fire outbreaks are mainly induced by humans, arising from backup generators during power cuts, uncontrolled flames from vendors cooking using charcoal, electrical faults (this includes substandard wiring, illegal connections, and overloaded systems), and residues from waste burning by food venders, with lightning a minor seasonal factor (Matemanga, 2023; Mboma, 2022; Hatmoko and Larassati, 2021; Twum-Barima, 2014). These identified eruption sources of fire, reported across Bangladesh, Tanzania, Indonesia, Ghana, Korea, and Nigeria are escalated into disastrous incidents by markets layouts of high-density, mixed storage, flammable materials, insufficient firefighting systems, and weak regulatory enforcement frameworks (Kim et al., 2007; Adeyinka et al., 2016).

The Fire and Rescue Force Act 2007 mandates all Tanzanian markets to be equipped with fire safety equipment, signs, and fire prevention, detection, and control infrastructure. Enforceability of this act has not been consistent and the majority of public markets lack the necessary firefighting equipment to respond to fire incidents promptly (Kachenje et al., 2010). The spatial organisation of Tanzanian markets, especially informal markets, also contributes to the issue. Narrow corridors, narrow exit routes, and poorly designed floor plans block fire prevention as well as the immediate responses of firefighters during emergencies (Mtani and Mbuya, 2018). It results in increased damage to property and poses serious hazards to life.

Many market fires in Tanzanian markets over the past few years make it imperative that fire safety be improved. Mbeya's Sido market fire on 15 August 2017, gutted more than 1,000 stalls, while the Tegeta market fire on 18 February 2020, resulted in heavy property losses. Other blazes, such as the 10 July 2021 Kariakoo market fire and the 30 May 2022 Temeke veterinary market fire, have inflicted significant loss to businesses, further burdening the economic costs of local communities. The 8 April 2022 Karume market fire and the 1 October 2023 Kariakoo Mart fire also inflicted serious loss on businesspeople and the surrounding neighbourhoods (Fig. 1-4). These accidents have raised awareness of the necessity for efficient fire prevention and control measures in Tanzanian local markets.

There is not much research on market design fire risk in Tanzania, although studies have primarily focused on markets in Dar es Salaam, including Kariakoo and Karume. However, there has not actually been a review of how market design can restrict fire hazards. There are several fires within the informal markets, especially in areas like the Mwanjelwa informal market. This shows that we need to have more research to identify how better market layouts and fire safety standards can minimise the risk and effects of fire incidents. This study will try to fill that gap by focusing on how Spatial Design can be utilised to reduce the risk of outbreaks of fire in Mwanjelwa local market in Mbeya, Tanzania. The recurrence of fires across these geographically dispersed markets, despite differences in scale and location, points to a shared set of underlying vulnerabilities that this study seeks to investigate through the case of Mwanjelwa local market.

Fig. 1. Karume market in Dar es Salaam – fire outbreak impacts. (Source: Africa-Press, 2022)

Fig. 2. Sido market in Mbeya – fire outbreak impacts. (Source: Wetu, 2017)

Fig. 3. Temeke veterinary market fire outbreak impacts. (Source: Daily News Tanzania, 2022)

Fig. 4. Kariakoo market in Dar es Salaam – fire outbreak impacts. (Source: Kolumbia, 2021)

2. Conceptual framework

While computational fluid dynamics (CFD) and Space Syntax analysis have long become integral to formal building design analysis, it is innovative to combine these two and apply them in an environment that is less researched in terms of risk interactions in an organically designed setting like that found in informal local markets within low-economy economies. This is because it is designed to specifically fit an unstandardised environment.

The study also looks at how informal spaces can be improved to reduce the risk of fires in local markets. It follows Environmental Design Theory (EDT), which addresses the ways in which physical settings affect human behaviour. This is based on Clarence Perry's idea called the 'neighbourhood unit concept', which he introduced in 1929. The idea has had a major impact on urban planning and subdivision development. The model was proposed to tackle problems like traffic, pollution, and isolation through the planning of space in a considerate way (Lamb and Vale, 2024). It has planned a people-friendly community with amenities like shops and markets on the edge, while inner streets are made safe for residents (Perry, 1929).

EDT suggests that safety, as well as fire safety, can be improved or hindered by the physical design and layout of space (Chianebeng et al., 2025; Tibesigwa et al., 2017). The concept advocates for the strategic design of public spaces to promote safer behaviours, foster better social relations, and reduce risks, particularly in crowded environments such as neighbourhood markets. Spatial features such as evacuation paths in the event of fires, stall arrangements, and access for fire trucks play a central role in preventing fires and in ensuring quick response in the event of outbreaks.

The concept is highly relevant to the current study, which aims at assessing the contribution of spatial design as an element of urban design in minimising fire outbreak risks in local markets, specifically Mwanjelwa local market in Mbeya. The study aligns with EDT as it examines how the existing spatial design features, such as the market layout, vendor location, and firefighting facilities, contribute to or minimise fire risks. By identifying the greatest contributing design factors towards fire outbreaks, the study will elaborate on how these climatic conditions can be modified to mitigate such risks.

The specific aim of the study in developing an effective spatial design model for local affordable markets falls within EDT's basic tenet of modifying the environment for improved safety and well-being. By incorporating fire hazard minimisation in market design, the study complies with EDT's requirement of designing spaces that not only ensure functionality but also safety. Additionally, the new model will adhere to environmental design concepts that favour reducing risks of fire while also catering to general accessibility and affordability of marketplaces to both vendors and customers.

Combining the EDT with other prior research variables, this study's conceptual framework takes into consideration the interaction between the principal variables as exposed by the prior research that affect fire outbreak risks within the situation of local markets. The principal variables are categorised into spatial design elements and fire safety precautions, which impact vulnerability elements and mitigation approaches. Moreover, it is contended that these factors outline the extent of fire outbreak risk, as can be seen from the figure below. The objective is to enable a thorough grasp of the underlying challenges towards working effectively in order to attain resilient and safer workplace environments within the local markets.

Environmental Design Theory suggests that physical surroundings have a real impact on how human see things, make decisions, and act. Instead of treating EDT as a framework for description, this study puts its ideas into action. It turns EDT principles into measure variables using tools like Space Syntax indices and CFD simulations (Xuchao et al., 2026). This framework details how smart spatial design boosts fire safety, connecting crucial concepts to specific, measurable results (Pradiptajati et al., 2026). It focuses on making it easier to find a way around by using clear, visually linked layouts that help people get their bearings and move quickly (Fu et al., 2024). It also promotes the importance of safe exits, with multiple, separate escape routes to avoid jams; reducing crowding by using appropriate wide walkways and gathering spots to lower density and prevent panic; controlling environmental stressors like smoke and heat through improved airflow; designing with vulnerable individuals in mind by guaranteeing access and visibility for emergency services; and establishing protected community zones with refuge areas located safely away from fire dangers (Madani and Choudhry, 2025).

The ultimate goals are quicker evacuations, less panic, better access for first responders, and greater protection for survivors (Hadiana et al., 2023a). CFD fire modelling has become the gold standard for predicting fire spread and occupant exposure in complex building geometries. European fire safety research has extensively validated CFD applications in commercial buildings (Chow et al., 2016). Space Syntax indices and CFD results are not just standalone technical measurements, but they are used to put specific principles of Evidence-Based Design into action. Each result from the analysis is connected to what users will experience. This systematic approach makes sure that EDT is integrated to methodology, instead of just being a theoretical idea that does not really affect the process (Fig. 5).

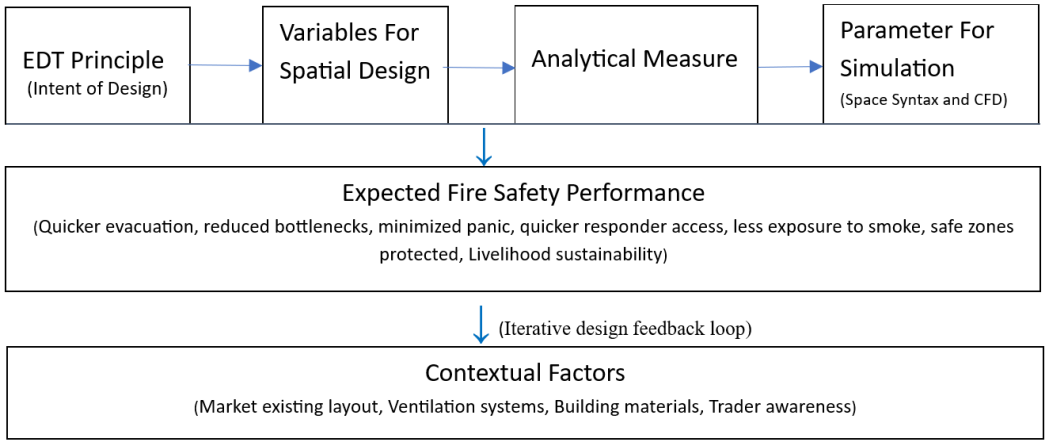


Fig. 5. The conceptual framework on EDT model–Evidence-based design for fire safety in markets. (Source: Authors, 2025)

3. Materials and methods

In previous studies on market fire safety, fire dynamics and socio-spatial aspects were generally regarded as two separate streams of analysis in relation to market fires (Spinardi, et al., 2016). In this study, however, CFD simulation using PyroSim and Space Syntax analysis were used in a manner wherein the results of the two methods complement and correlate. This approach intends not only to model fire propagation but also to model its dynamic interaction with the existing evacuation route vulnerabilities.

The study uses quantitative methodologies (QGIS, Space Syntax, CFD analysis, and physical measurement) and qualitative methodologies (observation, photo documentation, and interview). It is for ensuring an integrated understanding of the research issue through the strengths of both quantitative and qualitative information (Boddy, 2016; Creswell and Creswell, 2018; Matimbwa and John 2025). The study utilises a case study approach to conduct in-depth examinations of the real-world society events of the setting. Through this approach, it is possible to conduct an in-depth examination of the Mwanjelwa local market concerning its fire risks and spatial layout.

To provide a reflective and comprehensive analysis of spatial design and fire hazards in Mwanjelwa local market, the study utilised the case study method (Lavarda and Bellucci, 2022). The choice of location relied on its site-specific suitability and its representativeness of a wider market typology, on its particular relevance and nature to the study (Fig. 6). As compared to other local markets that were earlier evaluated, including Ikuti, Sido and Soweto, Mwanjelwa local market exhibits the structural, material, and operational characteristics that define informal local markets in Tanzania and across sub-Saharan Africa including informal markets in Ghana, Nigeria, Indonesia, and Korea (Abunyewah et al., 2022; Adeyinka et al., 2016; Hatmoko and Larassati, 2021; Kim et al., 2007).

Hatmoko and Larassati's (2021) systematic review of 60 market fires, both local and international, identified the same recurring vulnerabilities with extremely distinctive characteristics of fire risk indicators, including crowding, tiny exits, lack of fire safety equipment, use of open flames by food vendors, lack of fire safety awareness, the structure of the market is composed of highly combustible building materials and lack of fire response strategies. Mwanjelwa is therefore treated in this study not as a unique site but as an indicative case of a recurring market typology, with findings intended to inform the design of comparable informal markets in similar low-income urban contexts. These indicators made the site a good context for research. The spatial layout of the site and its functional characteristics align with the research objectives of both relevant and representative data.

Purposive sampling methodology was used, selecting 11 shopkeepers to gather their experience. Where observation could not provide sufficient data, interviews were undertaken as an additional method (Brown, 2006; Gallagher and Porock, 2010; Matimbwa et al., 2026). The selection of these respondents was justified by their market stay with knowledge of the market development origin, its operation, and perception of fire risks. Market vendors were not included due to the temporary nature that makes them less prone to providing elaborate information targeted at by the research. The study applied photographs in recording spatial qualities of the marketplace, with a place where sketches came to be used for expressing sophisticated spatial relationships, certain plans that could not be explained quite easily by photos alone.

The study applied a mix of different sophisticated tools and techniques to examine the collected data. It utilised QGIS to map the spatial layout of the market, including fire risk areas and evacuation paths. To digitise drawings and measurements obtained from field visits, AutoCAD was used to enable further analysis. To analyse the spatial relations, the study employed Space Syntax technique like identification of spaces with high traffic volumes and evacuation route effectiveness (Tsai and Chang, 2023). The CFD simulation was applied via the use of PyroSim aligned with Fire Dynamic Simulator (FDS) and Pathfinder software (version 2023.3.1206) to model evacuation processes as well as fire scenarios (Hadiana et al., 2023b; Zhang et al., 2022). The combined techniques for this research sought to enhance the validity and robustness of the research findings by ensuring data triangulation from multiple sources. The application of advanced analytical tools was crucial in ensuring the results are practical and accurate.

Fig. 6. Mwanjelwa local market in Mbeya region as the case study. (Source: Authors, 2025)

4. Results

4.1. Spatial design components

(a) Market layout

Market layout design considered several factors, including market size and population, method of escape, width and direction of aisles, assembly points, control of highly combustible products and materials, signs, lighting controls, and ventilation (Han, 2023; Manik et al., 2020; Jane et al., 2023; Mubita et al., 2023). The observations recorded the aisle widths of the market of varying sizes, ranging from 0.7m to 5.6m (Fig. 7). Variation in aisle widths affects evacuation and circulation efficiency. The market occupies a total area of approximately 127m by 141m that houses 522 shop stores, 4 food vendor stores, 47 storage rooms, 6 residential buildings in the middle, and 4 public toilet units. It was observed that there is a population increase in the afternoon through evening hours, enhancing the fire hazards.

It was revealed that the market has 29 exits, of which 23 are gates for security purposes (Fig. 8). It was seen that 12 exits are not directly connected to access roads. No emergency signage or space is provided around the market, where 7 out of 24 fixed fire extinguishers were in working condition. Because there is no designated centralised area for flammable materials, fire risks are higher. A satisfactory ventilation system was discovered to be the second problem that leads to restricted air circulation, especially during peak hours. The lighting system is dependent on energy from the public power grid, most traders have personal generators as their standby source of energy in case of power outages. The situation of improper electrical wiring in individual shops significantly increases the dangers of fires. The aisles are solid-roofed to avoid rain that hinders smoke evacuation in case of a fire.

(b) Accessibility

To determine the ease of evacuation within the market, the study assessed its accessibility during emergencies. Through observation, the study found the market has three access roads, of which only one is suitable for evacuation during emergencies. But the other two access roads are poorly linked to the market exit routes, indicating challenges to accessing the market during fire disasters. The issues for exit routes during evacuation are indicated in Figure 8 as highlighted in green.

(c) Building materials

By observation and interview, the study depicted that out of 583 shops, only 15 were wooden and the rest were built using bricks and blocks. 333 shops used gypsum board as the ceiling material, and 250 shops used wooden ceiling material. Wood and gypsum are boosting the risk of fire spreading because both have a very high percentage of being flammable.

(d) Construction techniques

The growth of construction at the market was gradual, the market was not executed as one work but was constructed in various stages in the form of self-help, depending on the owner's finan-

cial strength, requirements, and time constraints. This has resulted in a market design lacking uniformity, missing control of building materials, and causing hazards of fire.

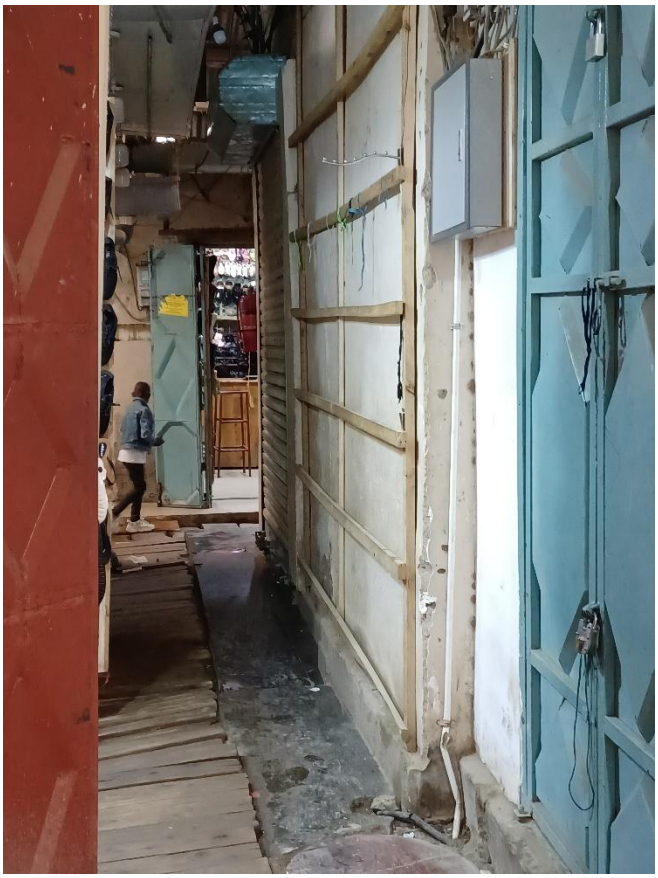
4.2. Building services and facilities

The study revealed that through personal initiative of constructing their own stores, the electrical installations were informally done by local artisans under little supervision, leading to poor workmanship. The situation greatly increases the possibility of fire outbreaks. It has seven water supply points, four of which are located in public toilets, one in the middle of food stalls, and two on the aisles. The pressure of the water flow, however, is not sufficient to serve firefighting purposes in case of emergencies.

4.3 Spatial and evacuation dynamics

(a) Market layout and spatial components

The results of the QGIS analysis facilitated the mapping of the contemporary status of the market with the aim of showing firefighting services, potential sources of fire, and exit routes. The exit routes, as illustrated in Fig. 9, demonstrate the consistency of the routes from wide to narrow, also showing the highly used routes. Additionally, the figure demonstrates the potential sources of fire such as cooking points for food vendors and residential buildings within the centre of the market.



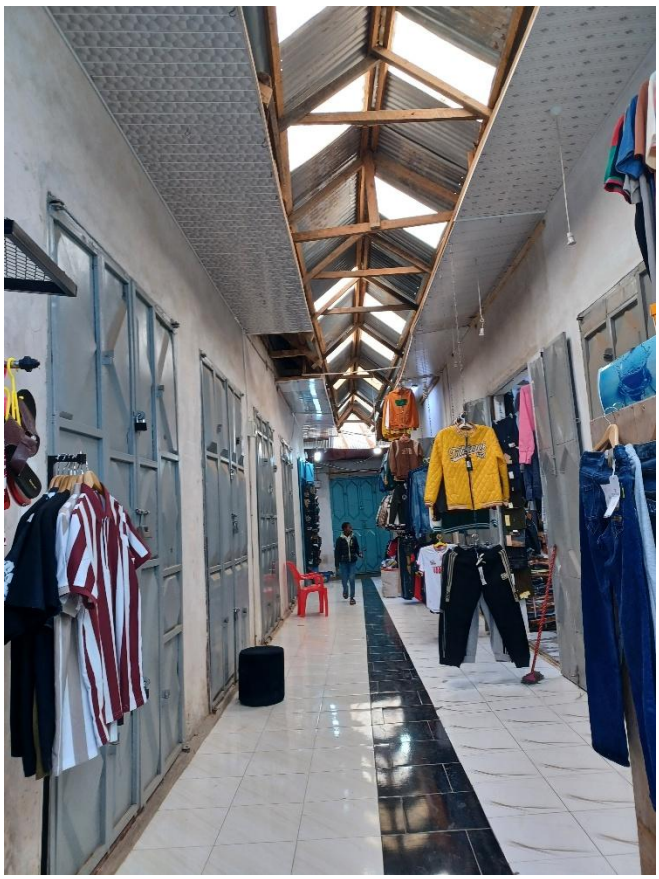


Fig. 7. Mwanjelwa local market aisles status – narrow aisles width. (Source: Authors, 2025)

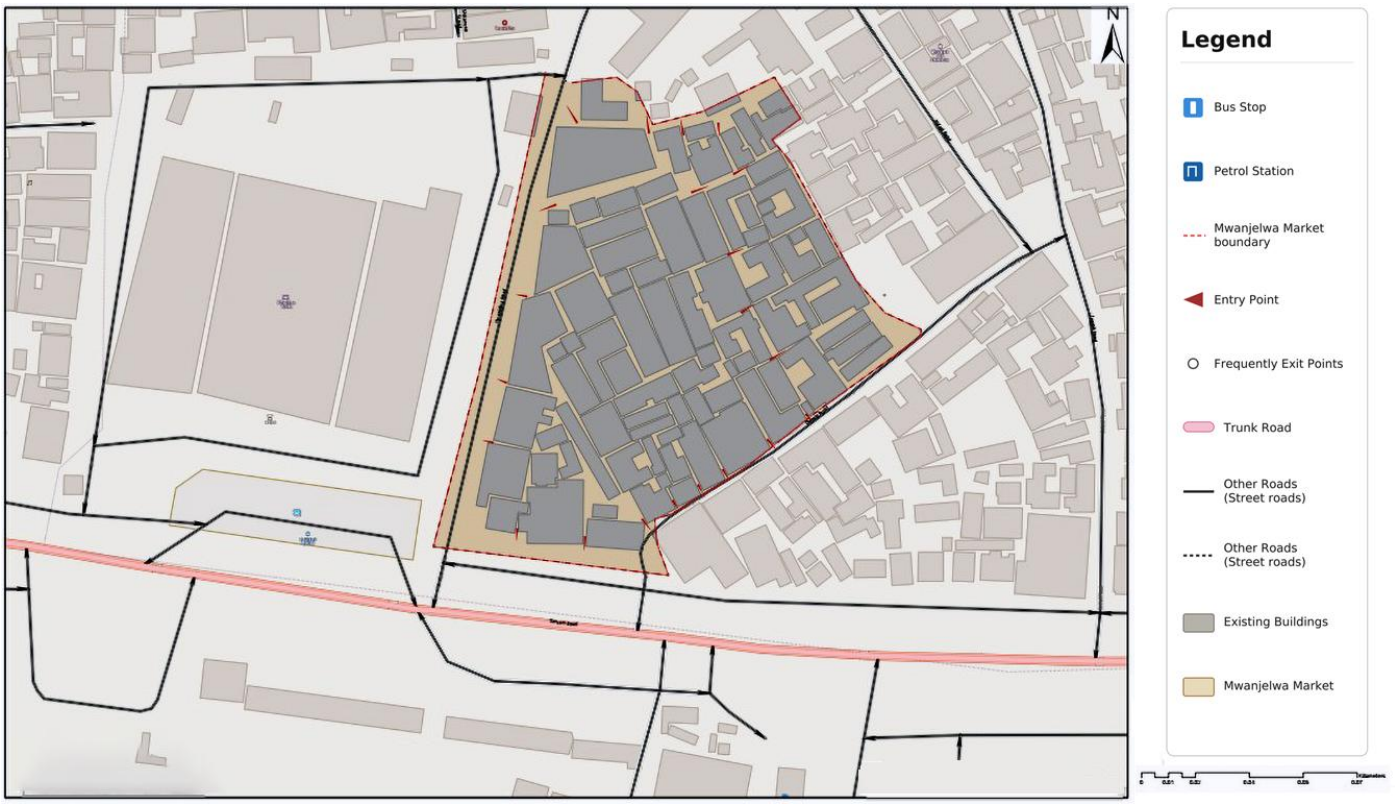


Fig. 8. 29 Exits versus connection to access roads of Mwanjelwa markets. (Source: Authors, 2025)

Fig. 9. Market escape routes, possible sources of fire, and firefighting equipment. (Source: Authors, 2025)

(b) Spatial integration and connectivity

Analysing market spatial relationship using Space Syntax has identified the areas of low and high connectivity as presented in Fig. 10. Areas of high connectivity are populated and have high circulation, suggesting the need for prioritised evacuation paths. The market, nonetheless, provides visual limitations (Fig. 11) to some of these areas through narrow and covered corridors,

which could hinder the evacuation process in case of an emergency.

(c) Evacuation process and time

By using Pathfinder software (version 2023.3.1206), the evacuation process was simulated, whereby occupants were classified into four groups: children, women, men, and elderly people based on their behaviour as established in Tab. 1. With 103 exits (every gate that faces the road is considered an exit) and 1,143 occupants, a variation of evacuation rate by groups was demonstrated in simulation, where men evacuated faster than other groups. This is evident in Fig. 12 with evacuation speed at 5-second intervals and Fig. 13 with occupants' speed and evacuation time relationship. Red-coloured market spaces with high social interaction were most prone to accidents and evacuation delays.

Tab. 1. Profile, speed, and width. (Source: Chen et al., 2018)

Profile	Shoulder width (m)	Speed (m/sec)
Male	0.500	1.50
Female	0.450	1.28
Elderly	0.439	0.80
Children	0.326	1.20

The above results and Fig. 14-17 reveal severe deficiencies in the market's fire safety measures from the perspective of spatial design. Inaccessibility, absence of building services, ineffective layout, and flammable building materials are considered high fire risks. Evacuation analysis illustrates possible challenges during emergencies, calling for the implementation of improved fire safety and spatial design procedures.

4.4. Vendor profile

A total of eleven vendors were interviewed, and selection of these vendors were purposively to capture a diversity of vendor types, commodity profile, gender, tenure, and stall locations within the market. Their profile summary is shown in Tab. 2. The interview findings reveal that the market involves diverse vendor statuses, demanding fire evacuation support, including assisted mobility, egress protocols, and designated and dedicated safe zones. Vendors in the market face sensitive risk resulting from potential physical barriers such as very narrow aisles and uneven floor surfaces. Also, require supplementary support like frequent evacuation drills tailored based on users' needs and available and reliable first-aid training.

Tab. 2. Profile of interview respondents at Mwanjelwa local market. (Source: Authors, 2026)

Interviewee	Vendor type	Gender	Tenure	Location	Commodity
1	Textile retailer	M	5 years	Central	Clothing
2	Food service	F	4 years	Near exit	Prepared food
3	Electronics vendor	M	2 years	Near exit	Electronics/cables
4	Textile wholesaler	F	12 years	Central	Fabric/shoes
5	Electronics	M	6 months	Central	Electronics
6	Food service	F	4 years	Peripheral	Cooking/prepared food
7	Textile retailer	M	6 years	Near exit	Clothing
8	Textile	F	2 years	Central	Female clothing
9	Mixed goods	M	1 year	Peripheral	Assorted
10	Textile	M	7 years	Central	Clothing
11	Food service	F	1.5 years	Near exit	Oil/food

Fig. 10. Connectivity between spaces. (Source: Authors, 2025)

Fig. 11. Visual integration. (Source: Authors, 2025)

Fig. 12. Evacuation speed at the interval of 5 seconds. (Source: Authors, 2025)

Fig. 13. Relationship between occupants' speed and evacuation time. (Source: Authors, 2025)

Fig. 14. Evacuation speed at 30 seconds before improvement. (Source: Authors, 2025)

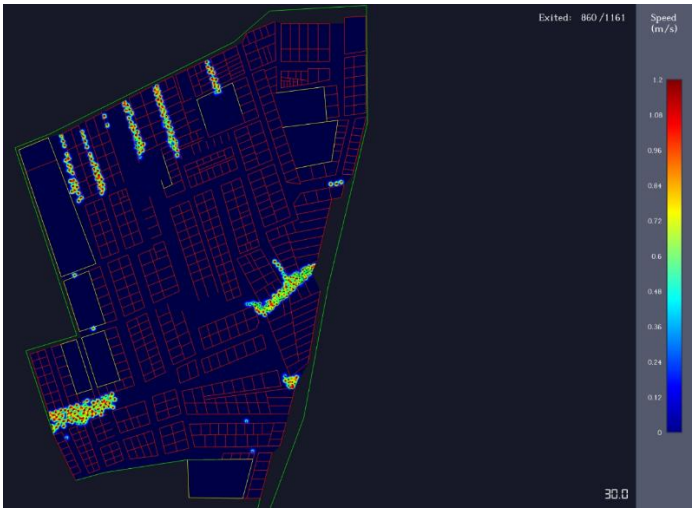


Fig. 15. Evacuation speed at 30 seconds after improvement. (Source: Authors, 2025)

Fig. 16. Evacuation speed at 60 seconds before improvement. (Source: Authors, 2025)

Fig. 17. Evacuation speed at 60 seconds after improvement. (Source: Authors, 2025)

5. Discussion

5.1. Theoretical implication

This analysis reframes spatial configuration as a key factor that amplifies risk in informal markets, going beyond standard evacuation metrics. By combining insights from environmental psychology and fire dynamics, the study reveals that poor spatial integration, measured using Space Syntax, directly hinders users' ability to understand their surroundings and perceive danger, leading to significant delays in their responses (Kustianingrum and Haerdy, 2025). This behavioural deficit is not just an individual problem but essentially built into the environment itself.

Moreover, the research uncovers a complex relationship within fire dynamics: inadequate spatial layouts cause evacuation flows to converge, which unexpectedly redirects smoke and heat towards people trying to escape. Using CFD, the analysis shows that better spatial integration and wider pathways do not necessarily resist fire directly, but they do facilitate a more dispersed evacuation (Fu et al., 2024). This helps with smoke ventilation and extends the time available for safe escape by more than two minutes, a potentially life-saving difference. These findings challenge traditional fire engineering by highlighting the interconnectedness of human behaviour and fire spread, which are typically treated as separate issues.

The implications of this extend to social vulnerability and spatial justice, revealing that fire risk is not evenly distributed. The research quantifies difference in evacuation ability for people of different gender and age between areas with high and low spatial integration. Consequently, fire safety is presented as a matter of social justice rather than just a technical problem (Richardson, 2019). The disproportionate risk faced by elderly, mobility-impaired, and migrant vendors in informal markets is, in part, a result of urban planning shortcomings that confine informal commerce to poorly designed spaces. Therefore, redesigning these spaces is a way to promote equity, with improvements particularly benefiting vulnerable populations. These three elements, environmental psychology, fire dynamics, and social vulnerability, work together to put into practice the core principle of Environment-Behaviour Theory (EBT) that environment and behaviour are inseparable. Through an integrated Space Syntax-CFD approach, the study demonstrates how physical layout directly influences survival outcomes.

5.2. Spatial design and vulnerability to fire

The research confirms that poor spatial planning and design are one of the contributing causes of fire risks in public local markets. The usual market aisles of 0.7m to 5.6m, the absence of well-signposted corridors for egress, and high population density of the market pose severe fire risks, as substantiated by studies in Indonesia and Korea (Khaerunnisa et al., 2024; Hatmoko and Larassati, 2021; Mtani and Mbuya, 2018; Seo et al., 2009). The crowded and narrow market circulation conditions are associated with emergency response times and fast fire spread, as well as reduced visual integration, thus creating delays during emergencies. The absence of functional firefighting appliances, as the study revealed, operating 7 out of 24 fire extinguishers, further points to institutional neglect, which indicates the need for intentional enforcement of the Fire and Rescue Force Amended Act of Tanzania (URT, 2021). The study also shows the improper smoke control, where the ventilation systems in the market were not sufficient to allow smoke to exit and people to evacuate easily as the visibility dropped. Through automatic ventilation systems, the smoke density will be easily controlled and will increase the available safe egress time (ASET) for the users' evacuation as the visibility increases.

5.3. Construction techniques and building materials

The presence of flammable building materials such as gypsum and wooden boards as ceiling members is revealed as a major cause of fire risks. The situation mirrors Mboma's (2022) findings that recognise the existing loopholes in the construction standards of fire-resistant buildings in Tanzanian public markets. The study material collected through numerical simulation has found the contribution of construction materials in fire spreading and evacuating residents' time. By comparison, non-flammable material markets exhibited lesser immediate risks, which suggests material control can minimise dangers. This is affirmed by existing literature that ceiling and walling materials contribute to the fire danger, whereas fire brick is the best future material that functions better for fire resistance in the event of less industrialised economies (Datta et al., 2024).

5.4. Human behaviour and evacuation challenges

The Pathfinder has determined major evacuation bottlenecks in evacuation simulations, especially in the market layout with low visual integration. Consumers and retailers within highly linked locations are trapped in congestion, resulting in escape delay, a phenomenon revealed in studies on Korean markets (Kim et al., 2007). Besides, the social linkage analysis of the study has shown that group behaviour made the evacuation process sluggish in favour of Chen et al.'s (2019) conclusions about crowd dynamics during emergency scenarios. According to the above results, the new and upgrading programmes must consider several points of exits, wider aisles, proper ventilation systems, as smoke is the main issue before fire, and holding public awareness about fire emergency regulations.

5.5. Regulations and practical implications

This study reveals loopholes in fire safety legislation, especially for informal public markets. Though Tanzania's Fire and Rescue Force Act demands safety equipment, there is low compliance with the law in local public markets. The concept of upgrading spatial design with the model proposing the presence of optimised evacuation routes, fire-retardant materials, and zoning of flammable textiles can become a scalable solution to existing local markets like that of Mwanjelwa. This linked approach implemented for the upgraded market in Seoul (Yi and Gim, 2018) can be replicated in the Tanzanian markets and elsewhere to reduce fire-related hazards. But it has to be technically incorporated with a focus on access that meets diversified needs without negatively impacting the incomes of local market traders, as is happening in some other industrialised countries (Suyanto, 2023).

The findings of this study can be applied to similar unplanned local markets in the region since they have similarities in practice and culture. The study has opened up other fields that must be researched, such as property evacuation strategies for such types of markets, whose current strategy was centred on property protection strategies and human evacuation. Apart from having in place a well-drafted Fire and Rescue Force Act of 2021 for Tanzania, the study advises future research into what policy enforcement mechanisms can be investigated to reduce fire risks in local markets.

5.6. Informal markets upgrading strategy in developing countries

A phased strategy for improving informal markets in developing countries, drawing from case study of Tanzania, addresses the challenges of general fire safety recommendations. These markets often struggle with budgets constraints and shop owners understandably focus on making a daily living rather than worrying about rare disasters (Mboma, 2022). The main idea is that these vendors not only are just breaking the rules but also making smart economic choices (Nelson and De Bruijn, 2005). Therefore, good policy should make it easier for them to act safely, rather than punish them. This plan balances reducing fire risks with the everyday realities of the informal economy through affordable, community-led changes over time.

Phase 1 could start with changes that are easy to achieve and do not cost much, including making aisles wider by having vendors rearrange themselves, keeping flammable goods away from things that could start a fire, putting up glow-in-the-dark exit signs, and launching a fire safety campaign within the community. Phase 2 would involve slightly bigger investments in the medium term, including paving main escape routes, using natural ventilation methods to help clear out smoke, and providing fire extinguishers along with training for vendors on how to use them. Phase 3 would involve more permanent construction changes, like adding fire-resistant sections, establishing formal market management, creating an emergency response system, and including the market in the city's overall fire safety plans. This strategy makes sure everyone benefits fairly through a gradual approach to funding, relocation support that protects incomes, prioritising local hiring, and offering free skills training. The approach is successful because it collaborates with existing vendor groups, prioritises early, low-cost improvements to gain trust, connects fire safety with economic progress, and strengthens local organisations instead of creating reliance on the government.

6. Conclusion

This research highlights the importance of the role of spatially informed design in addressing fire hazards in public markets, particularly in the context of low-income economies such as Tanzania, where market systems are critical to economic stability. By using Space Syntax simulation and Computational Fluid Dynamics (CFD) in combination, the paper contributes to the establishment of a new methodological approach to the evaluation of the efficiency of evacuation routes in informal market systems and the dynamics of fire spread. The results offer scientific evidence for the formulation of strategic interventions in the spatial design and infrastructural systems of the market environment. Among the significant recommendations for improving the market environment, such as the optimising spatial accessibility, formulating crowd management strategies, and using fire-resistant

construction methods, many are based on syntactic and fluid dynamics analyses. This paper contributes to the formulation of a better market environment using integrated simulation techniques, thus addressing the larger goal of economic stability in informal market systems.

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