Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03118-y

Towards a knowledge-hub destination: analysis and recommendation for implementing TOD for Qatar national library metro station

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Received: 23 July 2022 / Accepted: 6 March 2023

Abstract
During the past two decades, Qatar, a developing country, has invested heavily in infrastructure development to address several challenges caused by the rapid urbanization. Qatar has made a significant step toward its urban sustainability vision through the construction of the Doha Metro system. By adopting Transit-Oriented Development (TOD), Qatar is overcoming some urban challenges. TOD promotes compact, walkable, and mixed-use development around the transit nodes, which enhances the public realm through providing pedestrian-oriented and active spaces. Additionally, Qatar aims to transfer to a knowledge-based economy through developing an environment that will attract knowledge and creative human power. Qatar Foundation is taking the lead toward implementing a Knowledge-Based Urban Development (KBUD) through its flagship project: Education City (EC). This study aims therefore to evaluate the integration of TOD and KBUD strategies to leverage the potential of TOD in attracting knowledge and creative economy industries. The selected case study is Qatar National Library (QNL) metro station at the EC in Doha. The study examines the potential of QNL as a destination TOD to enhance the area's mission as a driver for a knowledge-based economy. The methodological approach is based on the analytical concepts obtained from the Integrated Modification Methodology as a sustainable urban design process. The study's results revealed that void and function, followed by volume, are the weakest layers of the study area's Complex Adaptive System which require morphological modification to achieve sustainability and a knowledge-hub TOD. The study offers recommendations to assist planners and designers in making better decisions toward regenerating urban areas through a knowledge-hub TOD contributing to the spill out of knowledge and creativity into the public realm creating a human-centric vibrant public space adjacent to metro stations.

Keywords Transit-oriented development (TOD) · Knowledge-based Urban Development (KUBD) · Education City · Qatar National Library (QNL) · Integrated Modification Methodology (IMM) · Livability · Sustainability · Doha · Qatar

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Published online: 24 March 2023

1 Introduction

> "All the cities of the world are going to expand. We need to have a better understanding of what makes good urban habitat for home sapiens. We have an obligation to make the new places more livable, more sustainable, more healthy. We have the tools." (Jan Gehl, 2010).

The city of Doha, capital of Qatar, has experienced rapid urbanization since the 2000s. It has grown and expanded on a vast scale following the governmental vision to globalize the country and participate in international events (Salama & Wiedmann, 2016). Massive expenditures on infrastructure development have accelerated the urban growth of Doha, leading to a construction boom driven by local, regional, and international investors (Salama & Wiedmann, 2016). The rapid urbanization has caused several challenges to the quality of urban spaces and lowered the potential for achieving sustainable urban environment (Al-Harami & Furlan, 2020). In response to such hurdles, the government of Qatar has issued a holistic urban development framework (Qatar National Vision, 2030 and Qatar National Development Framework 2032) aiming to transfer Qatar into a more sustainable country and improve the quality of life for its population (Qatar National Vision 2030, 2008). It has also recognized the need to adopt new development strategies to shift from an oil-based economy to a knowledge-based economy (Salama & Wiedmann, 2016).

In this regard, the government has endorsed a model for Knowledge-Based Urban Development (KBUD) aiming to build an urban environment that will attract knowledge and creative human power and assist in the transition to a post-oil knowledge-based economy (Alraouf, 2020). On one side, Qatar has been actively growing to fulfill its national vision, making considerable investments in constructing country-wide public transit systems. The Doha Metro is one of the most notable projects to support the current and future urban challenges by promoting transit-oriented development (TOD). On another side, Qatar has established a megaproject as a hub for knowledge and creativity, namely the Education City (EC), which targets local and global knowledge creation, discussion, and innovation (Alraouf, 2016). Transit-Oriented Development (TOD) and Knowledge-Based Urban Development (KBUD) are two different paradigms of socially driven urban movements embraced in the Qatar National Development Framework 2032. TOD catalyzes transit and land-use integration as a promising means for implementing sustainable development principles (Suzuki et al., 2013). KBUD promotes knowledge as a critical driver for urban development to attract creativity and innovation supporting a knowledge-based economy (Yigitcanlar et al., 2008).

This research study aims to examine the integration of TOD and KBUD strategies to leverage the potential of TOD in attracting knowledge and creative economy industries. It is based on a case study analysis for Qatar National Library (QNL) metro station at the EC in Doha. Specifically, the study focuses on examining QNL's potential as a destination TOD to enhance the area's mission as a driver for a knowledge-based economy. The research study is significant in two ways: theoretically and practically. Theoretically, it provides new perspectives in approaching TOD through KBUD strategies. Practically, it benefits policy makers, urban planners, and developers through providing valuable information on creating destination TODs and equip them with tools to achieve sustainable development. In fact, the review of existing literature, about TOD, shows that prior studies have emphasized on the importance of improving quality of life in order to retain creative knowledge workers

(Alraouf, 2018a). However, no studies have been conducted on the potential of TOD to support knowledge-based economies and creative industries. Findings of the earlier studies outline the advantages of the KBUD paradigm without significant reference to urban planning devices. Additionally, this study fills a gap in the literature by providing an overview of the integration of TOD and KBUD strategies from a uniquely Qatari perspective. Therefore, this research will enrich the literature by offering new thinking and novel approaches, to planning for TOD implementation, by fostering innovative ways of enhancing existing metro stations through KBUD strategies worldwide, and by helping in the advancement of knowledge-based economy for Qatar.

The methodological approach is based on the analytical concepts obtained from the Integrated Modification Methodology (IMM) as a sustainable urban design process. The IMM is utilized based on the modification and integration of the existing elements in the TOD area through research-by-design. This methodology is used as it enables researchers + planners to formulate more generic analysis for destination TODs, which should be relevant beyond the specific circumstances of Doha, and hopefully be significant globally.

The research paper is divided into five main sections. The introduction presents the research project's novelty and motivation. The literature review provides a scan of relevant concepts and studies. It also highlights the uniqueness of the results presented in this paper as compared to findings produced previously in related works. The paper provides new knowledge on the role of TOD in promoting knowledge and creativity. The methodological approach section provides a description and definition of the method and tools used for the data collection. It also presents the study area settings and details. The findings section presents the analysis and results of the study area and the proposed master plan based on the investigated design principles. The discussion and conclusion section considers the outcomes of the research and identifies gaps in the current urban design and presents an improved urban design framework pertaining to the study area.

2 Literature review

This section presents a review of the general concepts and interrelationships about sustainable urban development, transit-oriented development, and knowledge-based urban development, providing a framework for the study in Doha. A focused review of the local efforts to implement Sustainable Urban Development (SUD) in Doha is also attempted.

2.1 Sustainable urban development (SUD)

During the last twenty years, there have been significant efforts to highlight the potential of urban areas in promoting financial, social, and ecological development. The approach of sustainable urban development (SUD) has been a focus for international organizations and scholars who argue that planned urbanization leads to an improved quality of life, greater prosperity, and overall positive development (The Value of Sustainable Urbanization, 2020).

The fulcrum of SUD is sustainable cities that are defined as "urban communities committed to improving the wellbeing of their current and future residents while integrating economic, environmental, and social considerations" (Hoornweg & Freire, 2013). Well-planned and managed cities improve the overall quality of life and result in economic,

social, and environmental outcomes, which convert cities into catalysts for economic prosperity at the local and global levels (The Value of Sustainable Urbanization, 2020).

Sustainable cities are described as prosperous, accessible, livable, safe, walkable, affordable, and possessing vibrant street life (Furlan, 2015). Compactness, integration, and connectivity are three essential characteristics that create a framework for sustainable cities utilizing efficient street networks, high-density, mixed land-use, social mix, and limited land-use specialization (UN-Habitat, 2014). The knowledge city concept is closely tied to the advancements in Information and Communication Technology (ICT) which in turn can promote sustainable urban development (Monzón, 2015). The need for more holistic and integrated approaches to city making, as a viable path to heightened sustainability, has been underscored, including the development of an operational framework for design and planning (Sinclair, 2015).

2.2 Transit-oriented development (TOD)

TOD theories focus on the notion of urban areas designed for high-density development with high-intensity commercial and retail activities in a high-quality pedestrian environment (Curtis, 2008). Scholars define TODs as mixed-use urban developments centered around a public multi-modal transportation node that features urban compactness, connectivity, walkability, and cycle-ability (Al-Malki et al., 2022). Public spaces located close to the transport nodes promote walking or the use of public transportation instead of personal cars (Cervero, 2001; Cervero & Kockelman, 1997; Furlan & AlMohannadi, 2016; Kamruzzaman et al., 2016; Zandiatashbar et al., 2019). The distance around the station in TOD definition varies based on the context. A commonly used distance ranges from 500 to 800 m. However, higher distances arriving from 1000 to 1500 m are also used in Asian cities (Zhang et al., 2019).

TOD does not only deal with the planning of the transit stations; instead, it develops people-centered spaces for living, shopping, recreation, and social life (Cervero, 2001; Cervero & Kockelman, 1997), achieving a sense of community by considering the residents' socio-cultural behaviors (Furlan et al., 2019; Salat & Ollivier, 2017). According to Furlan and Sinclair (2021), cities worldwide are prioritizing "smart connectivity" as one of the primary urban planning elements. Smart connectivity not only involves sustainable transportation options but also includes non-motorized connectivity by offering safe, convenient, and comfortable pedestrian and bicycle networks.

In their studies, Calthorpe (1993), Cervero and Kockelman (1997), Knowles (2012), and Ogra and Ndebele (2014) have summarized six key features of successful TODS—the 6Ds: (1) Density: high urban density in the node catchment area; (2) Diversity: multi-purpose land use; (3) Design: livable, walkable, accessible, and connected design; (4) Distance: commute length to transit stations; (5) Destination accessibility: walking limits; and (6) Demand management: management of road transport.

Despite the demonstrable advantages, the TOD concepts are still, in many ways, in the planning stages. There may be a number of different causes and difficulties, which may be of an economic, social, environmental, or planning nature (Pathel et al., 2021; Alattar et al., 2021). These include regulatory obstacles like protracted permitting procedures, a lack of stakeholder commitment and community involvement, missed opportunities for land acquisition, and flaws in the framework for urban design (Lifam et al., 2021). The phenomenon known as "transit-induced gentrification" can be precipitated by rising land and house costs as a result of improved accessibility (Pathel et al., 2021; Al-Malki et. al.,2022).

Accessibility has been established as a key base in the development of creative cities (Wang, 2009). The basic infrastructure required to facilitate a knowledge city creation include the presence of high-quality public transportation such as TOD (Jones et al., 2006). TOD implementation principles, particularly relevant for this paper, are the creation of compact areas with short travel distances; human-centered public spaces adjacent to the stations; promotion of walkability and cycle-ability; planning for mixed-use; and provision of accessible and integrated public transit (Salat & Ollivier, 2017; TOD Implementation Resources & Tools, 2018). This can be used to assess the impact of a destination TOD to attract a ridership of young creative professionals by devising a creative city.

Customized TOD implementation is offered from the relationship between: (1) Node values: the relevance of a station in the public transit network; (2) Place values: the urban quality of a place and its attractiveness considering amenities; and, (3) Market Potential values: the unrealized market value of station areas (Salat & Ollivier, 2017). The essential principle of TOD is the application of context-sensitive and inter-dependent design standards, considering the variables at each station and its surroundings (TOD Implementation Resources & Tools, 2018; Zaręba et al., 2019). This is where the outcome of this research paper emerges: to present a case study for TOD's role in promoting knowledge and creativity to create destination TODs which are capable of achieving sustainable urban development.

2.3 Knowledge-based urban development (KBUD)

The knowledge economy evolution has become the engine of growth toward sustainable development (Alraouf, 2020). Knowledge-intensive industries and workers support urban prosperity and competitiveness in the global knowledge economy. By applying KBUD strategies, urban centers can prosper by attracting and retaining enterprises and human resources (Yigitcanlar et al., 2012). The KBUD paradigm envisions bringing financial advancements and environmental sustainability together with an improved quality of life by placing knowledge at the center of city planning and economic development (Alraouf, 2020; Yigitcanlar, 2012). From an urban planning perspective, knowledge precincts such as research centers, technology parks, and innovation hubs in proximity create a cluster in a geographic locale diffusing knowledge and providing positive externalities (Yigitcanlar, 2009). It provides a sustainable environment for knowledge-based products and services through enabling knowledge and innovation flows (Carrillo, 2006), supporting the constant creation, distribution, assessment, regeneration, and update of knowledge (Ergazakis et al., 2004). The sustenance of a KBUD requires demographic diversity, tolerance to differences, exceptional place-making attributes in addition to housing and entertainment amenities good enough to retain creative workers (Alraouf, 2018b).

Innovation and knowledge production are urban events resulting from adequate knowledge infrastructure, active street life, high diversity, and tolerance (Hospers & van Dalm, 2005). Knowledge precinct developments are central mixed-used environments, with interactive learning and playing possibilities that foster human connectivity within a "knowledge city" brand. The knowledge precinct is the venue of diverse local, national, or international knowledge clusters (Yigitcanlar et al., 2008). Knowledge precincts and knowledge cities are formed from knowledge spillover produced in creative urban regions (Yigitcanlar & Carrillo, 2009). Hence, urban space becomes a new economic asset attracting people, knowledge exchange and social networks, which requires adequate planning to contribute to the knowledge-based activities of the future economic sustainability (Martinus, 2012).

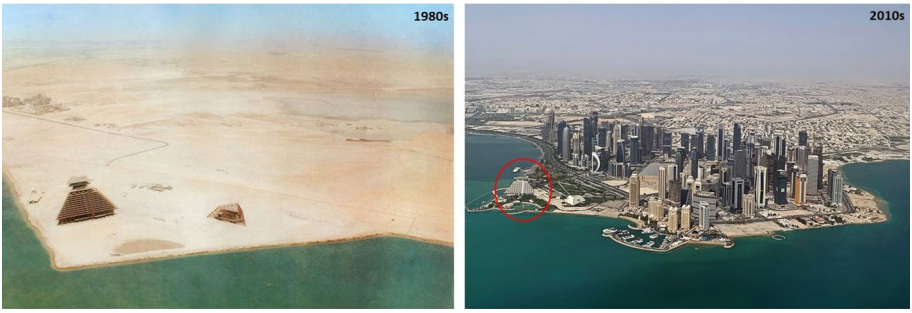

Fig. 1 Aerial view of the West Bay area in the 1980s and in the 2010s illustrating the massive urban growth, with reference to the Sheraton hotel building (*Source* Google Images; edited by authors)

Scholars have identified permeability as the critical feature of the urban space needed in KBUDs. A holistic and multi-layered permeability in spatial, social, economic, and environmental terms facilitate knowledge workers' progressive sense of place and place making. Blurred boundaries between the different functions, physical and visual connectivity, visibility of internal activities, active street frontages, and external vistas to surroundings are some aspects of the spatial permeability (Pancholi et al., 2017). However, the results presented in these previous works merely present the benefits of KBUD paradigm without any link to urban design topics or studies. This implies that the literature on KBUD should be enriched with interdisciplinary studies to provide existing research on the contemporary practices of architecture and urban design. Also, a significant topic can be investigated is the challenges and weaknesses of KBUD worldwide generally and in fast-developing cities specifically.

Vast relational networks can create knowledge. Thus, a knowledge city must embrace dense and correlated physical, social, economic, mental, and technological networks (Van Wezemael, 2012). Density, centrality, accessibility, social connectivity, and mixed-use are all vital components to fostering the creation of these networks (Rizzo, 2017).

2.4 Qatar's journey toward sustainable urban development

Qatar has become one of the most dynamic economies in the Middle East, particularly in the construction sector (Wiedmann et al., 2014). The years following 1995 are considered Qatar's globalization period, witnessing massive infrastructure and profound urbanization. For example, across the period of three decades, the West Bay area (northern part of Doha) has witnessed huge urban growth and global economic investments, in which towers and skyscrapers were largely built to accommodate hotels and headquarters (Fig. 1). With the presence of a national planning framework, the construction boom concerning land use, transportation, sustainability, fragmentation, and typology has been effectively managed to enhance the urban quality in Doha (Al-Harami & Furlan, 2020).

In the past decade, Qatar has recognized the need to adopt new development strategies utilizing architecture and urbanism to carve its space in the global competition among cities (Ahmed, 2018; Alraouf, 2016). In 2008, Qatar announced the Qatar National Vision, 2030 (QNV, 2030). It is a holistic development framework aiming to convert Qatar into a more sustainable country that provides high-quality life to its people by 2030 (Qatar National Vision 2030, 2008).

On a planning level, the Qatar National Development Framework (QNDF 2032), developed after the QNV, is a strategy to manage growth and build stronger, sustainable, and livable communities for the future (Furlan et al., 2019). By incorporating sustainable development features, mass transit, walkability, and mixed-use development planned around transit nodes, it intends to provide vibrant, engaging, high-quality public spaces. The introduction of the aforesaid new planning principles targets the transformation of Qatari urban areas into human-centered places. It also aims to create an environment that will attract knowledge sectors and creative human power to settle in Qatari cities. Such innovation is contributing to the knowledge economy and making the Qatari economic platform of the future ("*Qatar National Development Framework* ", 2016).

TOD introduction in Qatar targets the significant problems created during the country's phase of rapid growth and is moving the country toward more sustainable development. Additionally, TOD is promoted by Qatar's 2022 World Cup hosting, for which Qatar is committed to develop major public transportation networks, such as the Doha Metro and Lusail light rail transit (Al-Harami & Furlan, 2020; Furlan & Sipe, 2017).

The upgrade of the transit system in Qatar comes within the continuing efforts to establish Doha as an international service hub (Furlan et al., 2019). Connecting the city center to significant projects and transit nodes, the Doha Metro system aims to reduce private cars' usage while pursuing the TOD experience as part of the integrated transportation and land-use strategy (Furlan et al., 2020). Learning from the best practices of TOD, the case study of Doha has opportunities for TOD implementation in which transit nodes can be developed along the Doha metro system. The QNDF 2032 acknowledges the metro network as a significant public asset that should be optimized as part of the economic, social, and environmental development pillars of the QNV 2030 (Ministry of Municipality and Environment, 2016).

The Doha Metro system will have three lines measuring 300 km in length and 98 stations (Fig. 2) (Qatar Rail, 2022). Integrating the stations with their urban surroundings in a mixed-use and compact environment are the goal for successful TODs (Furlan et al., 2020). Stations of the Doha Metro are developed to support mix of uses through integrating retail shops inside which could be extended to the outside of the station in some locations. Planning for the station's context is critical to successful and vibrant place making. A good example is the metro stations which are located in business active areas such as West Bay in the north and downtown areas in Doha. Considering the socio-economic, cultural, and financial factors in the integration of transit systems and land use improves the efficiency and design performance of the transit nodes. For TOD to have a meaningful role in upgrading Doha's urban spaces, the tangible and intangible factors influencing the user's lifestyle must be carefully considered (Furlan et al., 2019).

2.5 Qatar's KBUD ambition and the role of Education City

The QNV 2030 aspires to position Qatar as a regional hub for knowledge featuring sustainable growth (Rizzo, 2017). The key factor in shifting from carbon societies to KBUD is attracting and retaining international knowledge residents (Yigitcanlar et al., 2008)—accordingly, Qatar has introduced innovative planning strategies to transform its urban centers into attractive places for such international residents (Ahmed, 2018).

The vision of Qatar as a platform for KBUD is clearly expressed through developments related to education, research, and knowledge dissemination (Alraouf, 2020). Among all the country's efforts and investments in this regard, Qatar Foundation for Education

Fig. 2 **A** Map of Doha Metro Phase 1 with three lines indicated; **B** interior view of retail shops inside one of the metro stations; **C** DECC metro station at the West Bay area illustrating the space for introducing outside retail shops; **D** aerial view of the metro traveling from the above-ground of Al-Wakra metro station (an adjacent city to Doha) (*Source* UN Studio; Qatar Rail; edited by authors)

Science and Community Development (QF) has taken the lead since 1995 as the largest organization in Qatar aiming at 'Unlocking Human Potential' (Ahmed, 2018; Alraouf, 2016).

The flagship project for QF is Education City (EC). It is a 12 square kilometer knowledge hub that houses international educational institutions and facilities, including all academic levels from early schooling to higher education. As a knowledge production hub, EC is the home of world-class facilities, including three national research institutes, a science and technology park, a high-end training and research hospital, a world-class convention and exhibition center, the Qatar National Library, a mosque, two museums, and an extensive art collection displayed across the campus buildings. This project went through several master-planning phases to plan for land expansions which required land use, transport, and landscape planning (Fig. 3).

The EC facilities are developed to support its community's wellbeing and overall health, for example it includes state-of-the-art sports amenities including a FIFA standard stadium, and several parks, promoting tangible applications of knowledge transfer (Alraouf, 2020) and fostering positive impacts of place and place making.

2.6 TOD as a driver for KBUD

Recent studies argue that TODs are essential for economic development, attracting creative incubators and knowledge economy drivers (Nelson et al., 2015). TODs may catalyze

Fig. 3 The land expansion of EC across the years (**A**) EC master plan concept in 2001 (300 Hectares); (**B**) EC first master plan in 2004 (614 Hectares); (**C**) EC integrated master plan in 2017 (1255 Hectares) (*Source* Courtesy of QF; edited by authors)

cluster dynamics improving knowledge production and dissemination (Chatman & Noland, 2011).

In their study, Zandiatashbar et al. (2019) highlight the positive effect of social interaction, networking, and knowledge exchange in providing firms with a competitive advantage. Stressing on the importance of location for knowledge and creative enterprises, the collaboration between large, medium, small firms, and freelancers grow in vibrant and busy creative environments. The favorable locations for these enterprises are walkable, mixed-use areas, quality urban space, and community areas that support social interaction (Pancholi et al., 2017; Zandiatashbar et al., 2019). Therefore, most TOD areas attract knowledge sectors and creative economy industries that highly benefit from such key locations (Katz & Wagner, 2014).

The concept of TOD and KBUD are closely related since the retention of knowledge workers in a creative city precinct necessitates the presence of amenities that improve the Quality of Life (QoL) of its residents (Alraouf, 2018a). Accordingly, the initiation of easily accessible and sustainable modes of transport centered around people places act as an attractor in improving commute between creative cities.

The era of KBUDs has increased people's mobility (Pancholi et al., 2017). Quality human mobility and meaningful interaction promote spaces that foster local creative and knowledge-based activities. Thus, the urban space in which these interactions occur is a potential knowledge resource. Quality urban space around transit nodes promotes urban vitality, human connectivity, and interaction, which are vital for KBUD implementation (Martinus, 2012).

To increase the impact of TOD on KBUD, more research should be conducted on how to integrate urban planning policies and strategies of both Innovation and Knowledge Hubs within the existing conditions and typologies of transit stations. Destination nodes provide access to unique areas with moderate to low-density, a mix of public and semi-public zones, and cultural uses supported by residential and local retail together constituting a 'Destination TOD' typology (TOD Implementation Resources & Tools, 2018). This type of node could be the suitable typology for Knowledge Hubs to implement TOD when supported with strategic land use and incentives to cater to educational organizations, training facilities, co-working spaces, start-ups, accelerators, and incubators (Katz & Wagner, 2014; Zandiatashbar, 2019). In fact, existing literature lacks studies and investigations on location analysis in relation to KBUD and TOD. Therefore, studies should be undertaken to analyze the location for accessibility and proximity to anchor institutions, creative enterprises, research and development, high-tech centers, and quality walkable urban space (Zandiatashbar, 2019).

3 The research design

The present research aims to: (i) investigate the potential of a destination TOD at QNL metro station to enhance the area's mission as a driver for a knowledge-based economy; (ii) analyze the existing site conditions following the Integrated Modification Methodology (IMM) developed by the Politecnico di Milano as a sustainable urban design process (Tadi & Manesh, 2013); and (iii) provide applicable guidance through masterplan recommendations for the Knowledge-Hub QNL Destination TOD. The research study is structured as follows:

Literature Review covering the following concepts from a disciplinary and geographical context: Sustainable Urban Development, Transit-Oriented Development, and Knowledge-Based Urban Development. The review investigates the potential of the study area for its transformation into a Knowledge-Hub Destination TOD and identifies integrated fundamental principles from TOD and KBUD to be followed for its conception.

In addition to aspects from the TOD's 6Ds, fundamental principles identified from the literature are utilized in this research: holistic permeability, the integration of large, small and start-up corporations with outstanding higher education and community engagement third places[1] in the mixed-use scheme, proximity to anchor institutions and quality knowledge producers, and a high-quality urban space (Katz & Wagner, 2014).

The findings follow the research-by-design approach and are structured into: (a) Site Analysis and (b) Master Plan recommendations. The methodology for urban studies known as research-by-design relies on the territorial analysis of the project area to produce a vision for its transformation through design prescriptions. (Furlan et al., 2020; Secchi, 2007; M.).

The site analysis explores the existing conditions by collecting visual data via site observation and visits, analysis of cartographic material, and interrogation of relevant content from the Education City Masterplan and Masterplan Integrator (ECMPI) reports. The latter is a series of reports integrating the fast-developing area after Arata Isozaki's master plan in 2004 and subsequent in-house design alterations (Moriyama & Tashima Architects, 2017).

The site analysis is performed following the Integrated Modification Methodology (IMM) concept, that is developed at Politecnico di Milano for sustainable urban development and already applied in many contexts worldwide (M. Tadi & Manesh, 2013;). The Integrated Modification Methodology (IMM) is a digital model-based procedure, aligned with UN-SDGs 2030, encompassing a set of scientific techniques for understanding the systemic structure of the urban settlements and propose modification scenarios to enhance their socio-economic and environmental performances.

In this methodology, the built environment is seen as a Complex Adaptive System (CAS) comprised of numerous subsystems interacting at various levels and scales. From this perspective, cities are ever-changing entities, transformation is an endless process, with network configurations providing a particular physical and provisional arrangement of the CAS.

IMM provides a deeper understanding of the morphological and socio-economic phenomena in specific urban areas, applying data engineering and modeling techniques to face the challenges posed by the heterogeneity and complexity of the problem at hand.

[1] Oldenburg identifies "third places" as the public places on neutral ground where people can gather and interact. In contrast to first places (home) and second places (work), third places allow people to put aside their concerns and simply enjoy the company and conversation around them (Oldenburg, 2002).

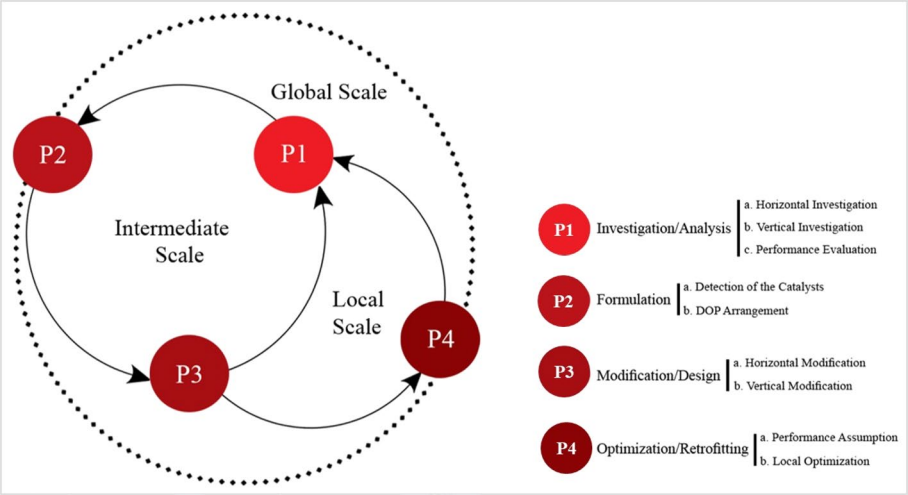

Fig. 4 Circular phasing process in IMM (*Source* Tadi et al. 2017; edited by authors)

Investigating the urban context as a Complex Adaptive System, the IMM analyses patterns of problems, and malfunctioning conditions to infer the source of the problems with the goal of improving the environmental and social performance of a specific urban contexts, in alignment with the Sustainable Development Goals. This methodology assists designers and decision-makers with a fully integrated design process plus a set of Design Ordering Principles (DOP) to transform an existing urban context into a more sustainable one (Massimo Tadi et al., 2017a, 2017b).

The IMM methodology is based on a multi-stage nonlinear phasing process involving the following structure:

- Phase I. Diagnostic: Analysis and Synthesis.
- Phase II. Assessment and Formulation.
- Phase III. Intervention and Modification.
- Phase IV. Retrofit and Optimization.

The Diagnostic phase by systematic investigation makes the identification of the cause or nature of malfunctioning condition or problems of the system the necessary step for any effective transformation process. The designer dismantles the CAS (Horizontal investigation) into its mains physical elementary parts, seen as subsystems by themselves and namely: Voids, Volumes, Type of uses, and Links/Transportations (Fig. 4). Then, through a Synthesis stage (Vertical Investigation) the designer examines Key Categories, a new combined organization which gives rise to the emergence of a new macro-level of organization that is a product of the synergies between the elementary parts and not simply the properties of the parts themselves. In IMM, key categories (Fig. 5. CAS configuration described by the synergetic integration between key categories (Source: Tadi et al., 2017b; edited by authors)) are namely: Permeability, Proximity, Diversity, Interface, Accessibility, and Efficiency. The primary outcomes of this phase relate to the comprehension of the physical arrangement of the CAS and unveils the weakest elements and mechanisms mostly responsible for the current performance. The performance of the system, however, has indicators

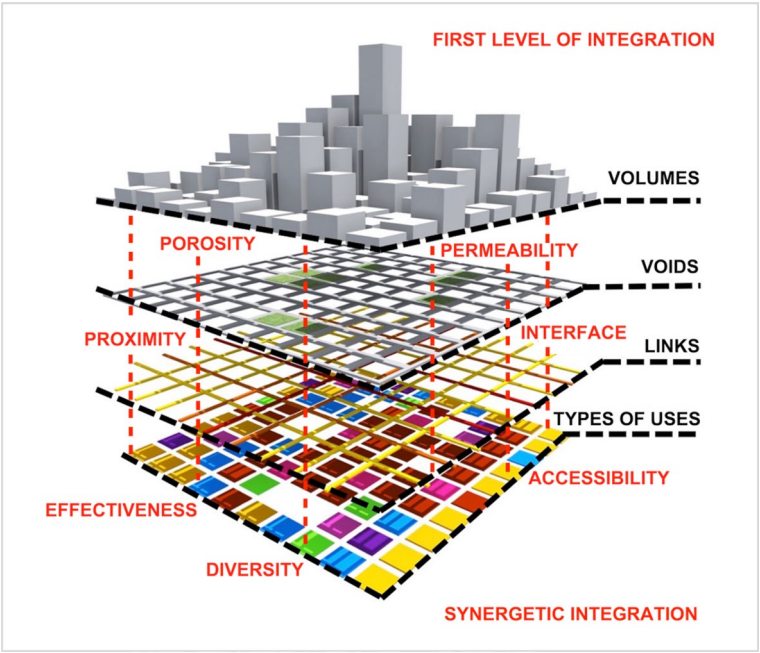

Fig. 5 CAS configuration described by the synergetic integration between key categories (*Source* Tadi et al. 2017; edited by authors)

of its own. A multi-final system like the built environment, naturally, demands many indicators to cover different aspects of its performance. Accordingly, IMM offers a list of 150 indicators clustered in 12 families to approach the performance of the built environment from different angles.

The second phase of the IMM process, named Assessment, and Formulation is the assumption of the weaker Key Category and elementary part as the first drivers of the transformation assigning them the catalyst role. From the selection of one basic component as horizontal catalyzer and one Key Category as vertical catalyzer, the reaction of the system starts, driving the local modification and activating the system's transformation. Formulation is the start of the design phase in which the Design Ordering Principles (DOP) play a great role as tools/instruments to modify the structure of the CAS and consequently affect its performance. As leading players of the Formulation Phase, DOPs work like active prescriptions, which, when combined, produce an integrated action toward the final goal.

The third IMM phase, named Modification, is a specific master-planning phase applied to transform the CAS structurally. Thanks to a driver assumed as Catalyst, the Horizontal modification sparks a local modification starting a chain reaction (Vertical modification) toward the global transformation of the CAS.

The last step is oriented toward the evaluation of the performance of the new CAS comprised of the modified subsystems. This phase, named Retrofitting and Optimization, revises the new provisional system, and compares it with the old one using the same procedure and the same Indicators already applied in in the phase I. After the transformation occurred a new system emerges becoming the new context available for new transformations, since the transformation is a continuous process (M. Tadi et al., 2017a, 2017b; Massimo Tadi et al., 2017a, 2017b; Tadi & Manesh, 2013).

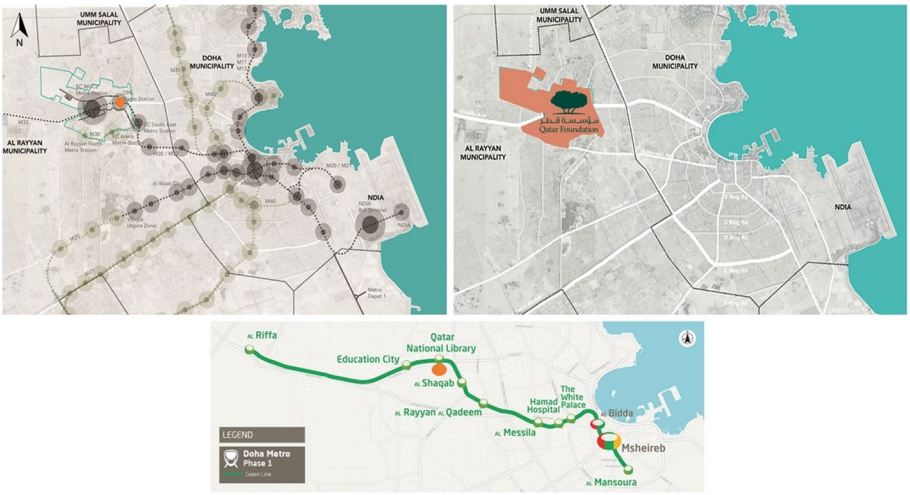

Fig. 6 EC and Doha Metro Green Line in context (*Source* EC location map courtesy of QF and Doha Metro Green line map courtesy of Qatar Rail; edited by auhtors)

The last section of the paper discusses the findings against the literature review to verify that the DOP prescriptions and their masterplan interpretation respond to the principles to transform the study area into a Knowledge-Hub Destination TOD. Subsequently, a conclusion is provided.

3.1 Case study setting

QNL metro station is located in Education City along the Doha Metro Green Line (Fig. 6). The study area is on the north-eastern side of Education City and is divided by Khalifa Avenue into two parts (North and South). Based on similar contexts, a radius of 1000 m has been considered from the metro station (Zhang et al., 2019).

Within the area limits, Qatar National Convention Center (QNCC), a portion of the Qatar Science and Technology Park (QSTP), and the Sidra Medical and Research Center (Sidra MRC) are located in the North. To the South, the study area comprises Qatar National Library (QNL), University branch campuses and Hamad Bin Khalifa University colleges (HBKU), EC Mosque, QF Headquarters, HBKU student Center, Oxygen Park, the ceremonial Green Spine, the Ceremonial Court, a portion of Al Shaqab Stables, and future expansion areas (Fig. 7).

4 Findings

The findings are structured into: (i) the site analysis, through the horizontal and vertical analysis of the CAS key categories, as identified through the literature review; (ii) and the masterplan recommendations addressing DOP emerged from the site analysis and reacting to the principles identified through the theoretical study.

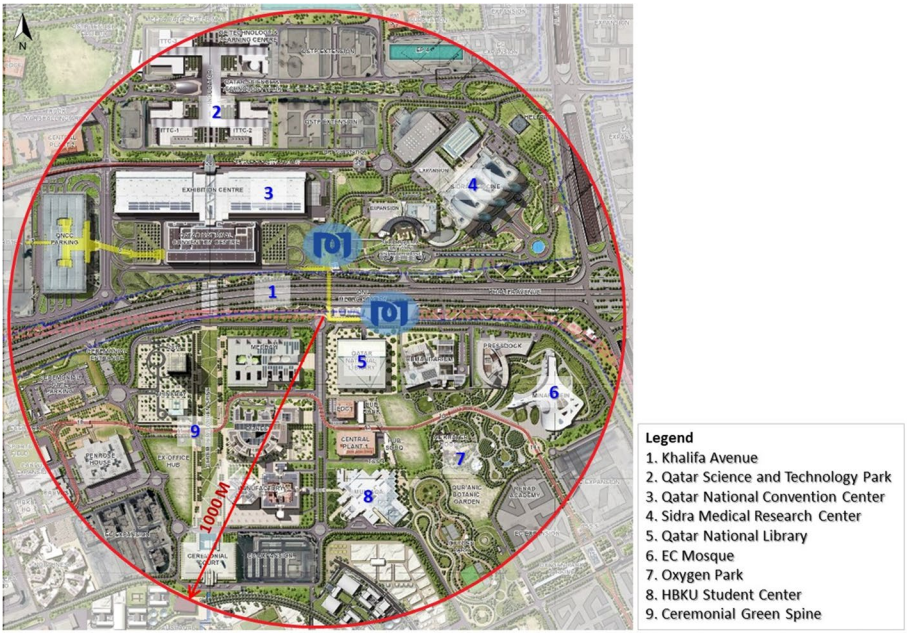

Fig. 7 Study Area Setting on EC approved Masterplan at time of the study (courtesy of QF; edited by authors)

4.1 Site analysis

As the Education City has not yet achieved its mature vision, the horizontal and vertical analysis of the CAS components is performed considering three different stages of the case study area (Fig. 8):

- The existing physical state of the study area.
- The existing MME approved Masterplan to examine the planned solutions.
- The ECMPI phasing plan to identify the scheduled implementation phase for probable existing solutions.

4.1.1 Horizontal investigation

The proposed strategy for the urban upgrade of the QNL TOD is derived from analyzing the urban system as per the IMM method through the horizontal investigation of its essential morphological subsystem layers: Volume, Void, Type of Uses, and links-Transportation. This is based considering the EC as a Complex Adaptive System (CAS) comprised of several subsystems which interact at various scales (Fig. 9).

The volume of the study area is characterized as a low-density, low-rise development. In general, the buildings are stand-alone with large footprints and heights of up to 16 m in height. Building footprints are smaller south of the avenue than they are north, providing a fabric that is more uniform. Large distances between buildings, wide roads, and vast open

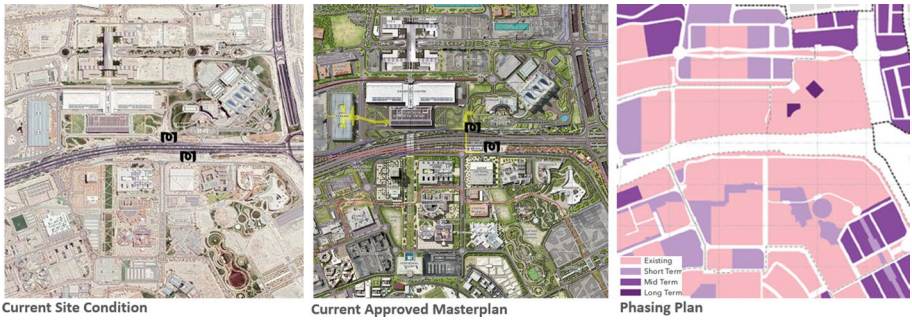

Fig. 8 Existing situation versus approved masterplan versus phasing strategy (*Source* Satellite image Google Earth. Master plan and phasing strategy graphic courtesy of QF; edited by authors)

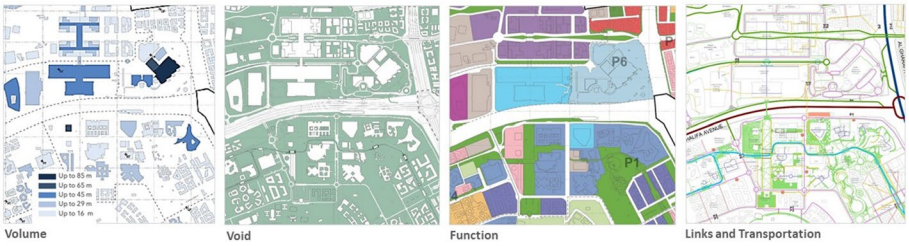

Fig. 9 Four morphological subsystem layers of QNL TOD illustrating maps of: volume, void, function, and links-transportation (*Source* ECMPI Reports courtesy of QF; edited by authors

green spaces generally characterize the study area's voids. The Northern side lacks centralized open community spaces, and the open areas are mainly landscape areas around the buildings or along the vehicular roads. To the South, the buildings are organized around two central open community spaces, the Ceremonial Green Spine, and the Oxygen Park (Fig. 10).

The prevailing use typologies are related to education, research, and community, alongside supporting functions such as office facilities and utility buildings. No residential component is found within the study area's 1000 m radius and active frontages are not available. Some minor services are installed within the buildings' main functions and tend to serve the building's direct community and EC community.

The open green spaces, the student center, QNL, and EC mosque are the only destinations offered to the general public at the south campus. Sidra MRC and QNCC are the public destinations to the North, having specific functions. A key observation is that the area's functions offer minimal visitor retention after working hours. It is also worth mentioning that QNL and QSTP can be considered anchor destinations of the study area. QNL is for all community segments, and QSTP is for researchers, start-ups, and entrepreneurs.

Regarding Links and Transportation, Doha, in general, is car-oriented which is reflected in the Education City. Despite the vision for a pedestrian-friendly campus, the prevailing attitude can be characterized as a car-driven culture. The inconsistent provision of shaded walkways and the lack of bike sharing facilities make the provided transportation options, such as the Metro, the recently Opened EC Tram, the internal QF Bus, the pedestrian and

Fig. 10 **A** View from the north illustrating the green areas around the buildings or along the vehicular roads and lack of community spaces; **B** view from the northwest showing the large distance between buildings and wide roads indicating the voids; **C** View from the south illustrating the organization of the buildings (*Source* courtesy of QF; Ashgal; edited by authors)

bicycle networks, a disconnected solution impeding a smooth transit and reinforcing the car as the preferred option for individual trips.

4.1.2 Vertical investigation

This study analyses the categories directly affecting the urban regeneration of the QNL TOD as a Knowledge Hub as identified from the literature review, namely Diversity, Design, Distance, Permeability, and Mixed-use.

The analysis is addressed through the IMM model to identify the gaps in the QNL TOD CAS and inform the formulation of strategies to modify the urban system (M. Tadi et al., 2017a, 2017b).

4.1.3 Compactness: analysis of permeability and proximity

Permeability describes the extent to which urban form permits or restricts movement of people, vehicles, or materials (M. Tadi et al., 2017a, 2017b; Massimo Tadi et al., 2017a, 2017b; Tadi & Manesh, 2013). IMM considers permeability, as a compactness attribute, which quantifies the level of organization of the urban texture, emerging from self-organized and synchronized states between the basic elements of the urban system. Permeability emerges by the combination and the synergetic integration of volumes, links, voids, and type of uses. In the context of KBUD, permeability also refers to the intangible permeability of knowledge and ideas.

Khalifa Avenue is a sizable longitudinal void with limited crossing options dividing EC's site into North and South and hindering flow. The access restricting QSTP Free Zone also compromises the flow to the north of the QNCC. Coupled with the missing and incomplete pedestrian and cycling connections in the area, the flow between facilities proves almost impossible. The functions are defined in their perspective plots with no active frontages or visual connectivity to indoor activities apart from QNCC main façade.

Meaningless boundaries related to early EC development and defining building plots within the South area restrict flow. Other restrictions are temporary and related to construction works and empty plots awaiting development (Fig. 11). Similar to the North, there are no blurred boundaries between functions, visual connectivity to indoor activities or active street frontages. Besides, the transition between open areas using buildings, as per the design intent, remains restricted.

Fig. 11 Permeability analysis—Volume and Void, and examples of existing boundaries (*Source* courtesy of QF; photos by authors)

Proximity is the morphological quality that the urban context offers for walking through the arrangement of primary types of uses. The primary types of uses are vital urban services, which might differ from context to context. In IMM, proximity emerges by the synergetic integration of type of uses, volume, links, and voids. Proximity is highly related to the pedestrian fruition of a space; the number of key function types that one can reach in walking distance (Massimo Tadi et al., 2017a, 2017b). The functions have been classified following Gehl as: Necessary Regular, Necessary Occasional, Optional, and Exceptional. Following ECMPI reports, a 350 m walking distance has been utilized as an acceptable walking distance taking up to 3 min walking from the buildings' main entrances (Moriyama & Tashima Architects, 2017) (Fig. 12).

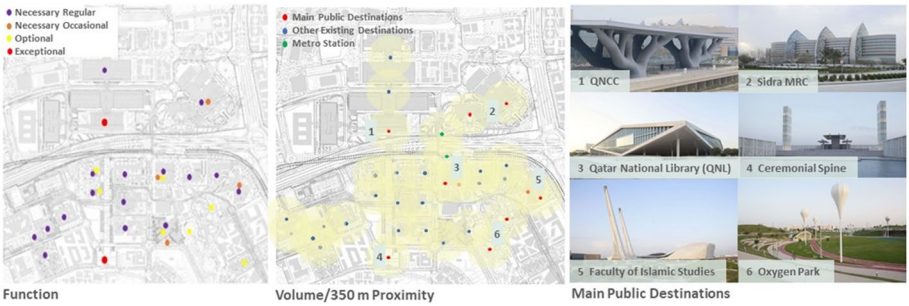

Fig. 12 Proximity analysis—integration of volume and function showing a convenient proximity to the QNL station and surrounding major destinations (*Source* Courtesy of QF; photos by Ewan Baan; edited by authors)

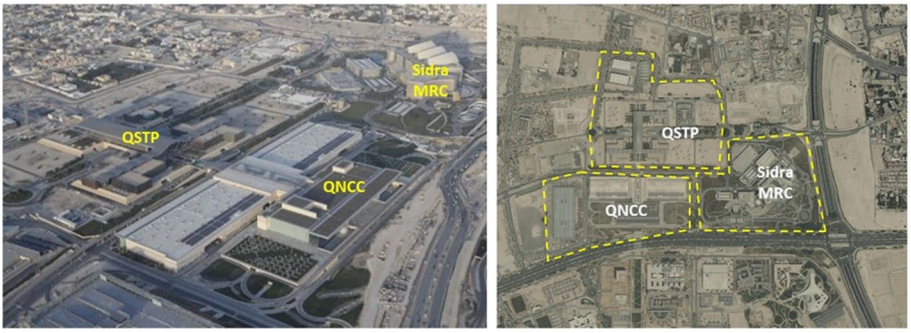

Fig. 13 Aerial and map view showing the disconnection between Sidra MRC, QSTP, and QNCC buildings and the lack of pedestrian accessibility (*Source* courtesy of QF; photos by Ewan Baan; edited by authors)

As per the Masterplan, most of the area's functions to the south of Khalifa Avenue are Necessary Regular functions with an identifiable cluster of enhanced proximity at the east of the QNL. Another cluster runs parallel to the Ceremonial Green Spine and across the Student Center to the Oxygen Park.

Major large-sized facilities related to community and research are located North of Khalifa Avenue. Although restricted only to pass holders, the QNCC and QSTP are connected through the EC Tram platform. The Sidra MRC is completely disconnected from the rest of the area's facilities. Additionally, missing and incomplete walkways hinder mobility and harm proximity in this area (Fig. 13).

In general, the proximity in the east of the Ceremonial Green Spine is medium to high when considering all functions. However, a dysfunction is noticeable when examining the proximity of the Necessary Occasional and Optional functions, except for the proximity between the EC Mosque and the Oxygen Park. It is essential to add that although facilities are within a walkable 350 m distance from one another, the walking conditions are not always encouraging. The lack of intermediate functions amplifies distance perception, especially in the hot summer months.

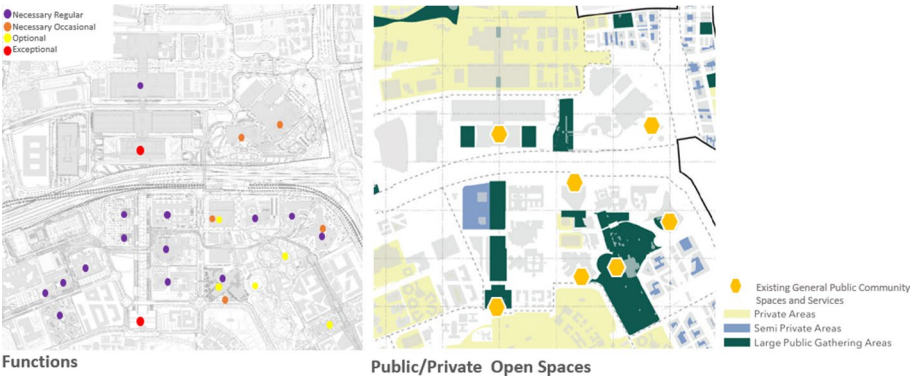

Fig. 14 Diversity analysis—Void and Function showing the lack of integration between functions and open spaces (*Source* courtesy of QF; edited by authors)

Fig. 15 Unused open space of building landscape areas (*Source* courtesy of QF; photos by authors)

4.1.4 Complexity: analysis of diversity and interface

Diversity contributes to complexity and underpins system level robustness, allowing for multiple responses to external shocks and internal adaptations. In IMM, diversity emerges by the synergetic integration of type of uses, volumes, voids, and links. To investigate diversity, it is crucial to define the key functions (Masera et al., 2020).

This analysis interrogates the function categories against the void, which is classified into large public gathering areas, semi-private, and private. The buildings' surrounding landscape is considered accessible for public transit but are not encouraging for gatherings (Fig. 14).

From the analysis, the lack of diversity in use typologies is evident. Single-function large-plot buildings, typically not publicly accessible, surround the major public gathering areas. Occasional services are mostly enclosed inside the restricted-access buildings, limiting social, and urban interaction with the open space. Furthermore, the absence of functions in and around the buildings' open areas and overlooking vistas, green spaces, and landmarks, is considered a lost opportunity for users and visitors' retention during and after working hours (Fig. 15).

Accessibility is the quality of allowing for main functions to be reached via public transportation systems in a certain amount of time (Tadi et al., 2014). In IMM, Accessibility emerges via the combination and the synergetic integration of links, type of uses, voids and volumes. The purpose of conducting accessibility analysis is because it enables us to understand the even or uneven distribution of key functions and transportation nodes. This

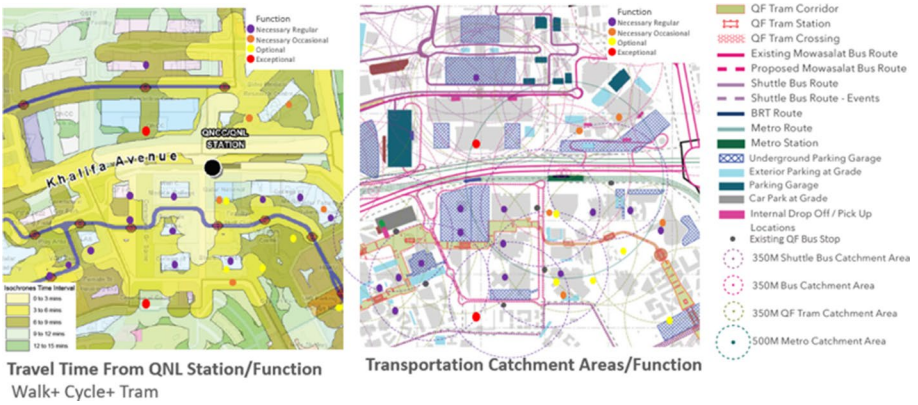

Fig. 16 Accessibility analysis—transportation-links and function (*Source* courtesy of QF; edited by authors)

means that the inaccessible areas in the city could be readily identified. It is noticeable that enhanced accessibility can be reached at the final development of the area and activation of all the envisioned transportation modes. However, at the time of the study, the EC Tram was not fully operational. There are no bicycles or other means of shared alternative transport. Additionally, the EC bus has limited and less integrated stops (Fig. 16).

Another observation is that the intermodal plaza envisioned for the QNL station-south is inside EC and does not allow direct connectivity from Khalifa Avenue. Furthermore, the intermodal plaza planned on the north side of the campus is situated at the EC Tram's final stop and is hence disconnected from the Metro station exit. Although not directly related to accessibility, improvement of signage, and availability of information proves essential as such gestures directly influence human behavior, including trending toward selecting a transit mode.

4.1.5 Connectivity: analysis of interface and effectiveness

The Interface analysis is a way to evaluate the integration of each street and pedestrian link within the global streets and pedestrian network (Tadi & Manesh, 2013). It gives precise information regarding urban flows. In IMM, interface emerges by the combination and the synergic integration of links, voids, types of uses, and volume. Within IMM, interface is assessed by the calculation of the mean depth, for each individual link. It increases the complexity of the system by increasing the number of possible links to connect two nodes.

The restricted-access points from Khalifa Avenue into EC cause a low interface thus providing limited accessibility. The same applies to the pedestrian and cycling links and Khalifa Avenue, which run parallel with few interface points other than the main EC gates.

Providing more direct connections to key destinations instead of the winding recreation-oriented walkways between the building blocks could enhance the pedestrian links interfaces. To the north, the restrictive nature of QSTP dictates a limited vehicular and pedestrian interface accentuated by missing and incomplete pedestrian and cycling networks.

The north and south sides of the avenue are connected through the Metro station tunnel. The pedestrian crossing at the QNCC proposed in the Masterplan, intended for enhanced connectivity, was not approved by the authorities and, thus, was replaced by

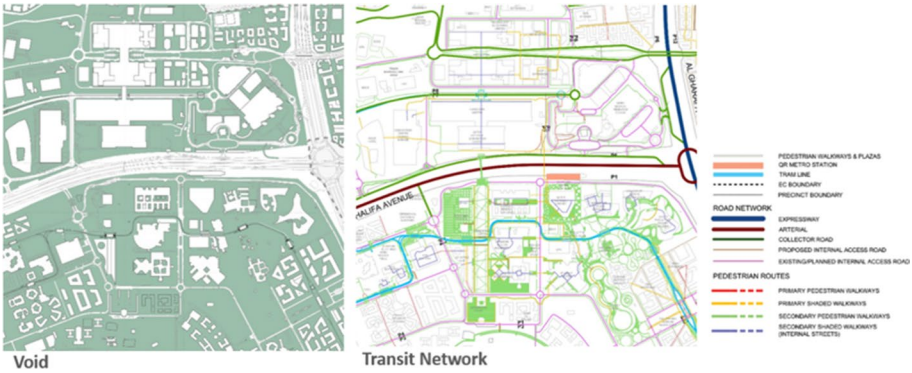

Fig. 17 Interface analysis—void and transportation-Links (*Source* courtesy of QF; edited by authors)

an at-grade crossing. Similar to accessibility, the enhancement of signage and wayfinding could improve the user's knowledge about mobility interface options and improve their usage (Fig. 17).

The effectiveness analyzes the relationship between the volume, the building blocks, and the transportation mobility system to identify the public transportation system's effectiveness to serve the study area (Massimo Tadi et al., 2017a, 2017b). Effectiveness defines the capability of the transportation to cover the built volumes around it. In the IMM, effectiveness defines the potential development within the intermediate scale. Highly accessible areas without any built volumes become areas of potential development within the intermediate scale. Areas deemed to have potential means that the transportation infrastructure exists, without any volumes around.

Like the accessibility category, the final development of EC with all its functional transit components will have an effective public transportation system and fulfill QF's vision for a pedestrian-friendly campus. However, the Metro and the uncoordinated EC Bus are the only current active transit modes, thereby leading to a significant effectiveness gap (Fig. 18).

4.2 Master plan recommendations

The DOPs ranking based on the catalysts selections and the systemic correlations among all the DOPs helps to shape the modification plan, normally in the form of masterplan recommendations (Massimo Tadi et al., 2017a, 2017b).

For the knowledge-hub TOD at the QNL station area, it has been found that void and function followed by volume are the weakest CAS components. A temporary weakness is identified in transportation/links leading to connectivity malfunctions. Thus, void and function will be investigated as the main modification catalysts to produce a masterplan and modify the rest of the CAS components. The above malfunctions directly impact compactness and complexity chosen as the main two determinants to guide the DOP and undergo the modification recommendations. Additional recommendations will be provided to temporary support connectivity.

For the Knowledge-Hub QNL—TOD, the DOPs (Design Ordering Principles) are categorized as per the below table (Table1):

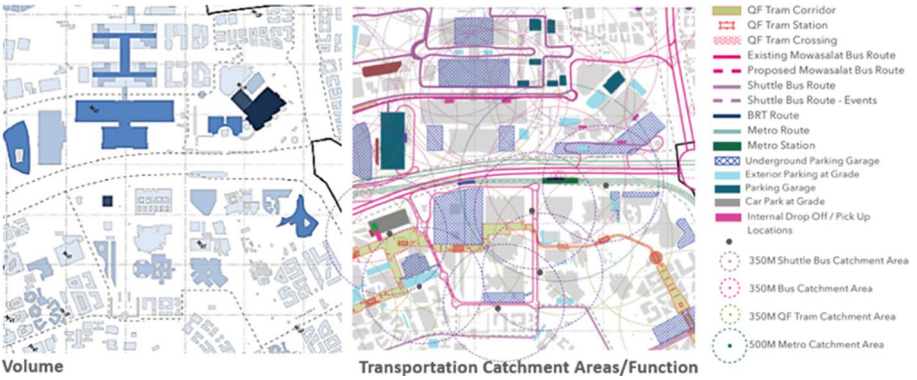

Fig. 18 Effectiveness analysis—volume and transportation-links (*Source* courtesy of QF; edited by authors)

Table 1 Ordering of the DOPs for the QNL—TOD

Design ordering principle	Key category	Determinant
Morphology		
Balance ground use	Permeability	Compactness
Improve flow	Permeability	
Reinforce walkability and cycling	Proximity	
Typology		
Develop a multifunctional urban space	Diversity	Complexity
Create connected open space systems	Interface	
Technology		
Reinforce intermodal stations	Accessibility	Connectivity
Align existing alternative transit modes	Effectiveness	

The DOPs for the study area are in alignment with the EC ECMPI objectives and strategies, enhancing ECMPI responses with no duplication (Fig. 19) corresponding to infill, mix, and connection from the six strategies of the ECMPI.

4.2.1 Balance ground use

To have a more porous structure and provide a higher integration between volume and void, the CAS's modification will start at the intermediate and small scale of the volume subsystem's morphological arrangement.

The implementation of RAKs (Relocatable Amenity Kiosk) and small-scale permanent interventions in line with ECMPI strategies is proposed. This activates more links between the urban nodes by establishing new connections (Fig. 20), providing more urban sociology inside the system, allowing for a wider variety of functions, and fostering more significant integration of spatial components (Ciric et al., 2016). Special attention is provided to open areas surrounding the large single-function buildings and the large public open spaces.

Fig. 19 Master-planning strategies and guidelines for the Education City issues and objectives (ECPMI) (*Source* Moriyama & Tashima Architects, 2017; edited by authors)

Fig. 20 Example areas needing physical and/or operational intervention (*Source* photos by authors)

4.2.2 Improve flow

The flow south of Khalifa Avenue is improved by eliminating unnecessary disconnections in the open space, removing physical barriers, providing direct connections at high traffic areas (Fig. 20), and enhancing signage. Besides, PPP strategies are proposed to expedite the development of the lands which constitute gaps in the urban form, identified for short-term development. Further to the physical interventions, operational adjustments are advised to allow permeability through buildings.

North of the Avenue a controlled pedestrian and cycling access is proposed at ground level for connectivity to QSTP and for enhancing the penetration of flow from the metro station (Fig. 21).

The major challenge is Khalifa Avenue. Since the municipality is installing pedestrian crossing bridges around the city, a simplified version of the initial Isozaki's crossing bridge designed during the masterplan development (Fig. 21) could be proposed to seek approval.

4.2.3 Reinforce walkability and cycling

Quick actions should be taken to reinforce walkability and cycling on existing networks. Firstly, by implementing the Shading Strategy and Signage Enhancement already planned projects. Secondly, by providing a series of interconnected activated urban spaces. The second objective can involve inserting a mix of functions in large unutilized outdoor areas creating urban plazas (Fig. 22).

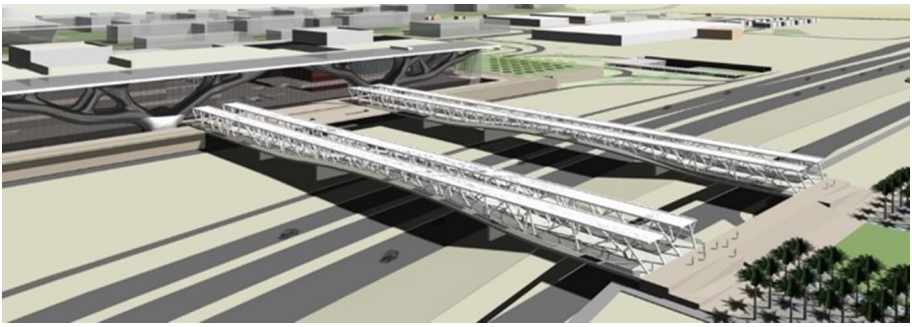

Fig. 21 Isozaki's proposed bridge crossing Khalifa Avenue (*Source* courtesy of QF; edited by authors)

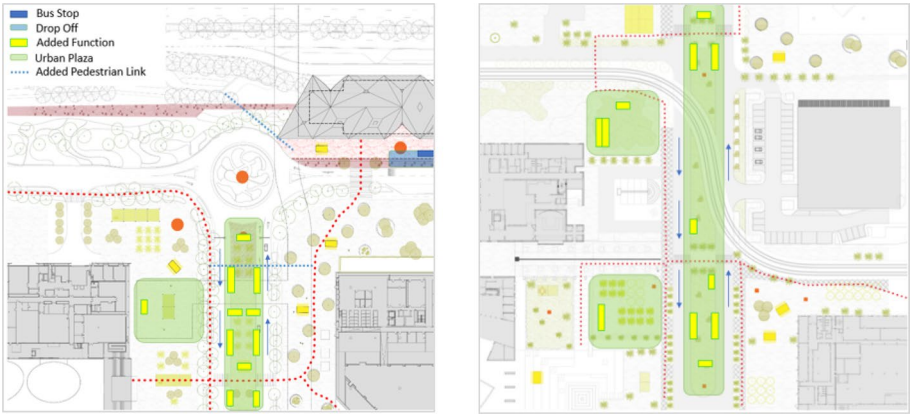

Fig. 22 Middle Island enlargement proposal and surrounding area interventions (*Source* ECMPI Reports; courtesy of QF; edited by authors)

A direct connection between destinations in high traffic areas will also enhance walkability and cycling as a means of transit, not only leisure.

Encouraging a PPP arrangement is proposed to bring in shared bikes and shared e-scooters, thereby utilizing the existing bike racks and networks around the campus and provide micro-mobility after arriving by Metro or being dropped off.

4.2.4 Develop a multifunctional urban space

This DOP involves a proposal to complement the envisioned mix-use developments as per the ECMPI with the injection of additional functions at three different levels:

- Infill small permanent interventions between buildings and in the proximity of open green spaces.
- RAK positioning between individual buildings, between buildings and open green spaces, and inside green spaces.
- Provide new Optional or Necessary Occasional functions inside the buildings accessible by the public or QF Community.

The proposal includes creating an axis parallel to the Ceremonial Green Spine in the form of a pedestrian plaza. Acting as a spillover of the surrounding knowledge creation institutions, the Plaza can incorporate the proposed permanent functions and activities. Enlarging the middle island at the road between the QNL and the university branch campuses, leaving only one lane per direction, will create sufficient space to fulfill that purpose (Fig. 22).

It is noted that the intended functions are to be an array of Necessary, Necessary Occasional and Optional. These functions could include training facilities, co-working spaces, and start-ups with interactive learning, playing, and networking opportunities. In this way, there is provision of a balanced mix that operates for prolonged hours during weekdays and weekends, promoting knowledge exchange, social life, and lively public spaces.

4.2.5 Create connected open space systems

This DOP aims to integrate existing disconnected networks and enhance green linkages to promote walkability and lively open spaces.

This study does not recommend any additional vehicular interfaces between Khalifa Avenue and the study area, supporting QF's vision for a car restricted campus. Nevertheless, improving the current pedestrian and cycling interface between the two projects is strongly recommended to provide connection nodes and better integration in transition and level differences.

A direct pedestrian and cycling connection are proposed to be enhanced and extended east–west at north of the Oxygen Park to arrive from QNL to the EC Mosque. This will improve the students and visitors transit from the Metro Station to the Mosque and Oxygen Park, providing opportunities for social interaction through the creation of outdoor Plazas (Fig. 23).

As previously clarified, connectivity issues related to shade, signage, and missing connections to the north of the Avenue are already accounted for in the proposal.

4.2.6 Reinforce intermodal stations

The currently proposed intermodal stations, as per the ECPMI, are located South of QNL and the Tram Stop 27 north of Khalifa Avenue (Fig. 24). To reinforce ease of transfer between the different transit modes, intermodal stations must be located at the Metro stations' exit.

At the south exit of the QNL station, this study recommends integrating a drop-off area and a bus stop from the campus side, expanding EC bus services to cater for the public arriving through the Metro. Another proposed enhancement is introducing a car-sharing service.

At the North, the intermodal plaza should be relocated at the Metro exit. It should include a bike and car-sharing stations and a shuttle bus service to allow accessible alternative transit in that area and enhanced connectivity to the tram stop. It is recommended that the above actions be activated as soon as possible as they are crucial for the rest of the DOPs' success (Fig. 25).

Future intermodal stations will be activated when the EC tram becomes operational campus wide. Their interaction with the main car parks will provide intermodal connectivity between cars, the tram, shuttle buses (for events), and bikes/e-scooters. For this stage, it is also recommended that the service of shuttles buses or BRT, as mentioned in the ECMPI, be

Fig. 23 South of the avenue study area with proposed interventions (*Source* courtesy of QF; edited by authors)

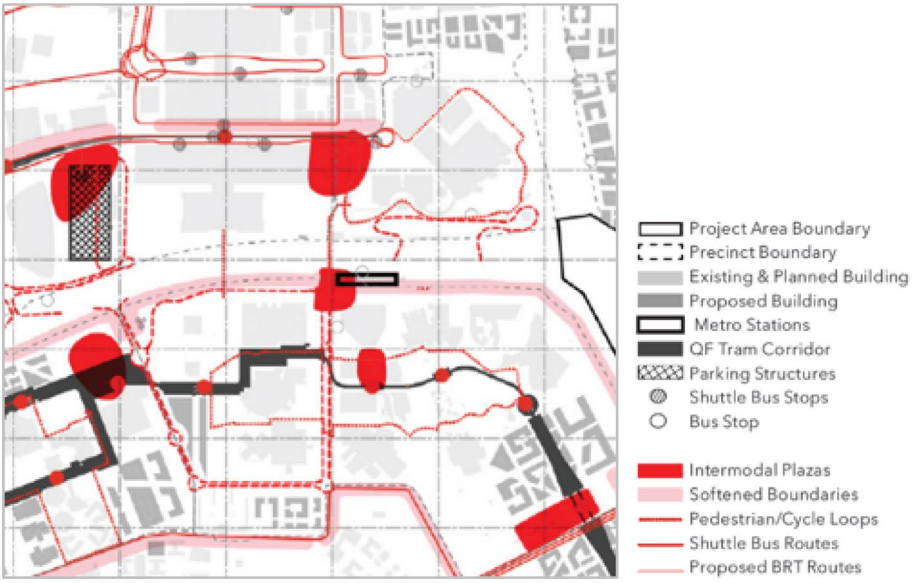

Fig. 24 Planned intermodal plazas (*Source* courtesy of QF; edited by authors)

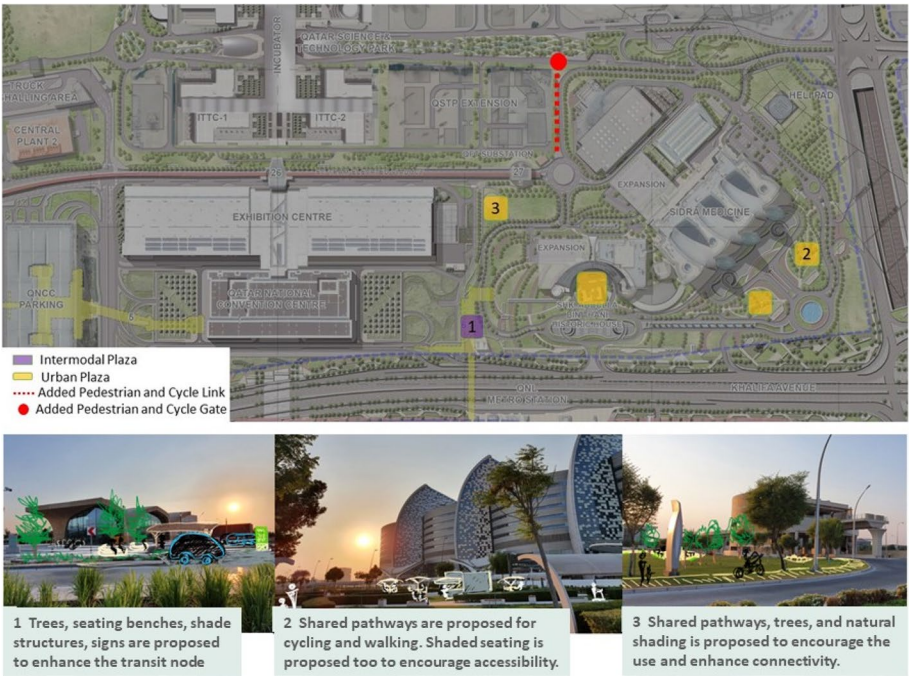

Fig. 25 North of the avenue study area with proposed interventions sketches (*Source* courtesy of QF; edited by authors)

expanded to become a transit option within the campus for the commuters using public transport or parking at one of the public car parks.

4.2.7 Align existing alternative transit modes

This DOP enhances the temporary transit situation until EC's fully activated transit plan is achieved, at least for the South of the Avenue, which is more frequently visited and has more users. The DOP suggests minor enhancements that could make a significant difference to passengers utilizing the Metro.

The first recommendation is to relocate the existing EC bus stop a few meters away from the Metro to a location that is more visible and accessible by Metro users—better allowing for enhanced public usage. The second recommendation, mentioned earlier, is related to implementing PPP strategies. For example, to bring in a third party to provide and operate a shared bike system to utilize the available and ready to use infrastructure. This DOP will also benefit from enhancing signage and availability of information either directly onsite or through an app, as recommended by the ECMPI (Moriyama & Tashima Architects, 2017).

5 Discussion and conclusion

> "While there are clearly unique regional and national perspectives on urgent matters pertaining to the sustainability of our planet, and there are multiple definitions and interpretations of modernity, some strategic and systemic steps (universal in applicability and pervasive in potency) can be advanced.
> These steps, by necessity, must be contemplated and contextualized within a greater ethos of values and beliefs." (Sinclair, 2015).

Qatar has made a significant step toward sustainable urban development with the Doha Metro construction following QNRF and Qatar Vision 2030 guidance. QNDF stresses on developing TOD at metro stations to link transit nodes to the surrounding urban environment encouraging public transport use and sustainable urbanism.

At the QNL station, a further opportunity arises from the peculiarities of the station context positioned within Qatar Foundation's Education City, one of Qatar's prominent manifestations of KBUD. Leveraging on existing site potentials, the area lends itself to be designated as a Destination TOD dedicated to knowledge and innovation.

The findings identified through the site analysis show that void and function, followed by volume, are the weakest layers of the study area's Complex Adaptive System (CAS), which require morphologic modification to transform the performance of the CAS into a more sustainable one targeting the goal of Knowledge-Hub TOD. The comprehensive approach for the urban regeneration targeting such transformation must be grounded on a planning methodology for enhancing compactness and complexity and increasing permeability as the critical feature of the urban space needed in KBUDs. Some modifications to the existing high-quality urban realm are necessary to improve walkability and heighten outdoor social interaction.

Similar to urban planning principles, the idea of knowledge cities already emphasizes the permeability paradigm, which includes concepts like openness and flexibility in the field of "soft skills" such as creativity, inclusivity and freedom of speech (Hall, 2004). The extent of knowledge dissipation in other knowledge city clusters in the Middle East such as the Knowledge City, Dubai Internet City and Media city in the United Arab Emirates (UAE) is limited due to the mere presence of these clusters as business and community infrastructure rather than as innovation clusters (Alraouf, 2018a). From a planning perspective, this necessitates a need to collaborate with other institutions, and improve physical and ICT integration for a spillover effect.

The state-of-the-art mono-functional large-building blocks in the Education city, and the underutilized open areas between them, paired with the time and resources required for implementing the ECMPI recommendations, have led the city's urban realm to be perceived by users as non-friendly for walking or cycling. In fact, such perceptions have led to the use of the private car as a preferred transit option by most commuters. The underuse of the open areas between buildings has resulted in the lack of urban plazas, outdoor gathering areas, and sitting spaces. Moreover, restricting passage through the buildings as a shaded and cooled option for pedestrian transit has further impacted the development's walkability. Thus, the area's regeneration through a Knowledge-Hub Destination TOD must contribute to the spill out of knowledge and creativity into the public realm and transition those aspects toward more human-centric vibrant public spaces adjacent to the station. Additionally, earlier studies have highlighted the negative impacts of reducing creative knowledge clusters to gated cities (Alraouf, 2005, 2018b). Several examples

such as the Sudan Electronic City (SEC), Mubarak Scientific City of Cairo, and King Abdullah Economic City (KAEC) in Saudi Arabia have been under scrutiny due to their limited accessibility and a distorted understanding of KBUD (Alraouf, 2018a). Such urban development patterns hinder the promises of a knowledge city by restricting access to certain sections of the society and promoting segregation (Vesselinov, 2008). In the case of EC, an integration masterplan was carried out as a part of the efforts to combine the disparate structures to a holistic sustainable and functional model while upholding its initial aim to inspire human excellence. This is achieved by enhanced compactness and short commutes, the promotion of walkability and cycling, the provision of vibrant context-based mixed-use, fostering human connectivity, accessibility, and integration with a good quality public transit.

These study findings target predominantly the TOD area's activation at the station's southern exit. The northern exit area findings propose limited interventions focused on enhancing connectivity due to the specificity of the functions of the areas' mega-buildings and, in particular, QNCC, which will require further studies on the implementation of TOD at large scale convention and exhibition avenues to achieve a more sustainable, compact, vibrant, human-centric urban space.

All in all, the present paper contributes to the body of knowledge through reconsidering the implementation of TOD in Doha through innovative KBUD strategies, emphasizing the role of the public realm in creating places that attract and engaging people in daytime/nighttime activities throughout the year. A well-functioning public realm is based on accommodating a well-defined network of public spaces where people's movement is easily facilitated from one place to another. The introduction of enhanced connectivity and accessibility around the QNL metro station, supplemented by additional modes of integrated transportation such as bicycles, walking, public buses, and tramcars, will enable people move efficiently across the scale of the EC. Quality of life in our cities, including the creation of rich, diverse, supportive, enjoyable, healthy, resilient, and sustainable spaces and places, must be our priority.

Acknowledgments The authors would like to acknowledge the support of Qatar University in providing a work environment which facilitates and motivates scientific research. The authors would like to thank the leading engineers and key professional people working in governmental agencies and municipalities in Qatar, specifically those in the Ministry of Municipality and Environment (MME), the Ministry of Transport and Communications (MOTC), Qatar Rail, Mowasalat, and the Ashghal Public Works Authority. Their cooperation and collaboration with the authors were crucial in the development of this research study. This included meetings, the provision of visual materials, guidelines and frameworks, and discussion of future plans. Finally, the authors would like to thank the reviewers and editors for their invaluable feedback.

Funding This research study was developed under the grant scheme awarded by Qatar University, Grant ID: QUST-1- CENG-20/21-16, titled "A Holistic Strategy for the Urban Regeneration of the Souq Waqif Neighborhood". Open Access funding was kindly provided by the Qatar National Library (QNL).

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