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Temporal Model for Mitigating Urban Development Uncertainty

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ABSTRACT

Many factors impact the quality and efficiency of urban development plans. Political, environmental, economic, logistical, and social aspects are among many other factors that have long and short terms impacts on development projects. It is difficult to predict these factors and their impact through all the implementation phases of any long-term regenerative or large urban development projects. The central area of Makkah city has been under major development over the last fifteen years. This development was planned through a set of multi-billion dollar projects. These projects were developed by private sector consortiums. Each one of these projects follows its own design, development strategies, timetable and cash flow schedules. These projects were reviewed and approved by the local authorities. The authorities main concern was to control the quality of services of these projects as well as applying municipal regulations. Strategic objectives in terms of innovation or sustainability, timetables or cash flow of these projects were never reviewed or aligned together by the authorities. Since these projects cover the old historical city and they all apply demolition and rebuilding policies, their impact on the overall city was huge. Therefore, it was critical to keep monitoring and predicting the urban changes through the life span of the implementation of these projects. This is why, the main objective of this research is to develop a temporal 3D GIS model for evaluating, monitoring and predicting the urban changes of Makkah central area after fifteen years of development implementation and analyze the factors that impacted its evolution. To achieve this objective, a 4D GIS model was built to track the urban changes and construction progress through the last fifteen years (regeneration period). At the same time, it was useful in comparing the planned changes in the initial plans of each project with the existing situation. Moreover, financial, political, institutional, and administrative factors affecting these changes, in its course of implementation, were identified and their impacts were analyzed. The paper findings suggest that any urban plans are vulnerable to external uncertainties during the implementation of long-term large development plans. Coordination, co-operation and flexibility are required to address external uncertainties through the implementation phases. Finally, it concluded with a set of recommendations regarding development factors and the degree of flexibility required through urban development projects to achieve their objectives under the impact of uncertainty. (386).

1. Introduction:

1.1. Objectives:

To develop a temporal 3D GIS model for evaluating, monitoring and predicting urban regeneration, define and analyze different aspects impacting it.

1.2. Methodology:

To achieve its objectives, the research followed an analytical approach where, a temporal 3D GIS model was built for the case study "Historical Makah area", urban changes through the last two decades were time tracked and analyzed, affecting aspects were defined and their impacts were concluded.

1.3. Limitations:

Despite that the case study used data were enough to achieve the research objectives, it worth mentioning that some of the used data were inconsistent and some others were out of date. A more accurate and up-to-date model needs to be developed in case more accurate results and assessments are required.

1.4. Utilization of GIS in Monitoring & Predicting Urban Change:

Identifying the spatial relationships, norms, characteristics, and land-use change of any urban area is essential as a preliminary phase for any urban development or regeneration project. Various approaches have been developed to model and simulate the urban dynamics and their impacting factors. **(Arai, 2004) (Liu, 2005)**, **(Jun Luo, 2008)**. Barmelgy argued that complex systems such as urban systems are better represented through dynamic models where differential equations with at least one-time derivative are used for any function in time. **(Barmelgy, 2019)**. Data about change through time assist urban planners to reconstruct changes in buildings and understand urban transformations. Nocerino suggested that multi-temporal imagery can be used for purposes like investigating urban change dynamics over time, interactively presents and monitoring changes of heritage sites. **(E. Nocerino, 2012)**. As GIS analytical tools and techniques developed in the last decades, they enriched activities related to urban development and urban changes' monitoring and prediction. **(Jun Luo, 2008)** These tools provide good support to the development activities and help in achieving its objectives. **(Carpenter, 2011)**. In his work, Nocerino found that 3D GIS modeling techniques would be more useful if the time is linked to the 3D model. Moreover, he proved that this 4D model facilitates documenting and analyzing consequently predict changes of the urban fabric, capacity, services and road network as well as buildings across urban area. **(E. Nocerino, 2012)**. Linking urban spatial data to time gives them a perception of the changes' patterns over time. The importance of the 4D GIS comes from linking chronological information for spatial objects. Moreover, it facilitates utilizing the created models in developing scenarios for patterns of urban geo-

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spatial changes over time. **(Barmelgy, 2019)**. They give a more realistic and clearer perspective of the forces affecting the urban system by taking into consideration urban changes dynamically. **(Barmelgy, 2019)**

Several projects during the last decades prove that Geomatics technologies, such as GIS, provide useful tools for urban modelling and planning. Mapping three-dimensional spatial urban data over time is and has been useful in monitoring, developing and predicting urban changes. Many researchers have presented urban projects that successfully utilized GIS in urban development projects. Khalid mentions several projects in this aspect, monitoring land-use changes in Bhubaneswar city, India during the period 2000-2005. It was also utilized in studying the urban expansion of Madurai city during the period 1991-2006. Moreover, the dynamics of urban expansion of greater Cairo, Egypt was modelled and quantified during the period 1972-2005. (Khalid AL-GHAMDI, 2012)

Geographic Information Systems provide a good tool for tracking change over time. This can be achieved through creating one GIS system for all the central area projects; including their basic information and proposed time schedules. This system should be used to track change throughout the development period. In the representation of urban systems, many changes occur in any of the values of the constituent parts of the urban system or affect its represented variables within the model. (Barmelgy, 2019). The current research addresses several changes such as architectural style, floor area ratios, capacities, built-up area and even excavation work and removal of a large percentage of mountains and levels. Holy Makkah represents a good example that is hardly available in any other city, as the central area of Makkah was going through major development urban projects for the last ten years and still going. It was hard to follow up on these urban changes and their impacts or even predict these changes and their future impacts on the city unless a 4D GIS system is built and implemented to track these projects and their changes over time.

2. Theoretical framework:

Figure 1 illustrates the sequential phases of creating the 3D temporal GIS model to monitor urban changes over a certain time of time and analyze the impact of its events, linking those events to their causing factors to overcome the uncertainty of the development. This is followed by creating scenarios for future changes and at the end predicting future urban conditions and deciding needed steps to improve development outcomes. The model consists of four sequential stages, data collection of urban development plans and their timetable, creating 3D Geodatabase, adding temporal information to facilitate the analysis at the end.

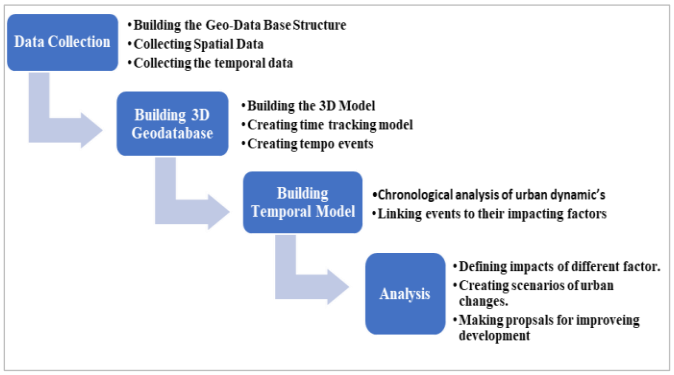

Figure 1: Framework for monitoring urban change information to predict uncertainty

3. Case Study:

3.1. Urban background:

Historically, Makkah city has been confined within a small valley surrounded by mountains. The urban growth extended on the slopes of the surrounding mountains, Figure 2 illustrates the small valley and its surrounding mountains. As shown in Figure 3 urban fabric of this old area is characterized as a compact fabric with a narrow irregular shaded road network of alleys. Building heights do not exceed four floors, as shown in Figure 4. (Fayez Zuhair, 2004 AD.)

Figure 2: Mountains surrounding historical area of Makkah within Ibrahim valley

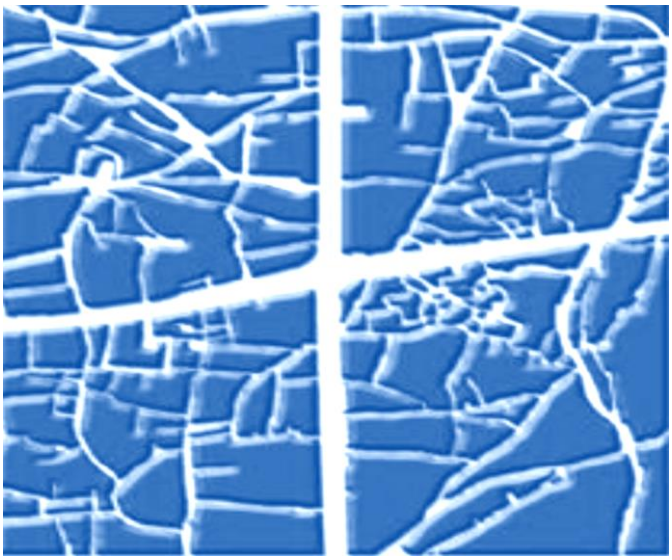

Figure 3: Makkah conventional urban fabric

Figure 4: Example of architectural style and urban spaces of the historic area

During the Eighties, Makkah witnessed major urban changes. Saudi first and second expansions of the Grand Mosque were accompanied by a series of tunnels linking the historical city with its surrounding valleys, particularly Mina Valley and Al Azizah Valley in the east and Al Hijrah area to the south. These tunnels facilitated the expansion of the city area for the first time in thousands of years outside the limited valley towards the newly developed areas as shown in Figure 5. Unlike the historic areas of Makkah, the new urban expansion has a western style in its urban fabric and architecture style in terms of its buildings' heights; road width and pattern as sown in the picture in Figure 6. (Fayez Zuhair, 2004 AD.), (Ahmed M Shehata, 2017).

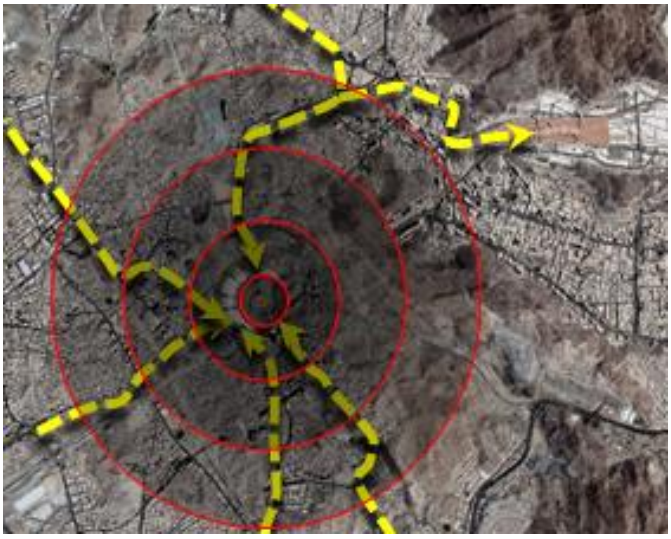

Figure 5: Current urban growth boundaries of the City of Makkah

Figure 6: Urban type in the newly developed expansion areas

3.2. Characteristics of Ongoing Development Projects:

The City of Makkah is witnessing major development projects and consequently a dramatic urban change that is rarely witnessed in contemporary cities. The historic center of Makkah is currently undergoing a comprehensive replacement within huge projects aimed at replacing the historic face of Makkah with another contemporary one, the face of which the features are not clear yet, but the central area will certainly change during the coming decade and it will lose its known urban character and architectural style; and acquire a new face and features. Figure 7 illustrates the size and location of the urban development projects concerning the city urban area.

3.3. Development Projects in Makkah Central Area:

Development projects vary in their capacities, area or even building heights. There are four major projects with large areas: Jabal Omar, Jabal Khandama, Al-Shaniya and the parallel road. Buildings of these projects are based on the law of volumes and a maximum of 22 floors, but there is a tendency to increase heights to cope with the high land prices. The clock tower project reaches 570 meters in height to become the tallest concrete skyscraper in the world. The following is a brief overview of the most important architectural and urban features of these projects. (Authorities, 2005). Figure 8 presents the development of the projects during the last two decades, while figure 9 illustrates the proposed architectural style of some buildings of the development projects. (Shehata A. M., 2012)

Basic Information about the main project:

4.3.1 Jabal Omar Project:

Project area: 320000 m^2

Estimated capacity: 34500 persons

4.3.2 King Abdulaziz (Parallel Road):

Project area: 514000 m^2

Estimated capacity: 55000 persons

4.3.3 Jabal Al Kaaba Project:

Project area: 46000 m^2

Estimated capacity: 40400 persons

4.3.4 Endowment development project:

Project area: 430000 m^2

Estimated capacity: 25000 persons

4.3.5 Al-Shameiah development project:

Project area: 430000 m^2

Estimated capacity: 570000 persons

4.3.6 Khandama Area development project:

Project area: 225000 m^2

Estimated capacity: 35000 persons

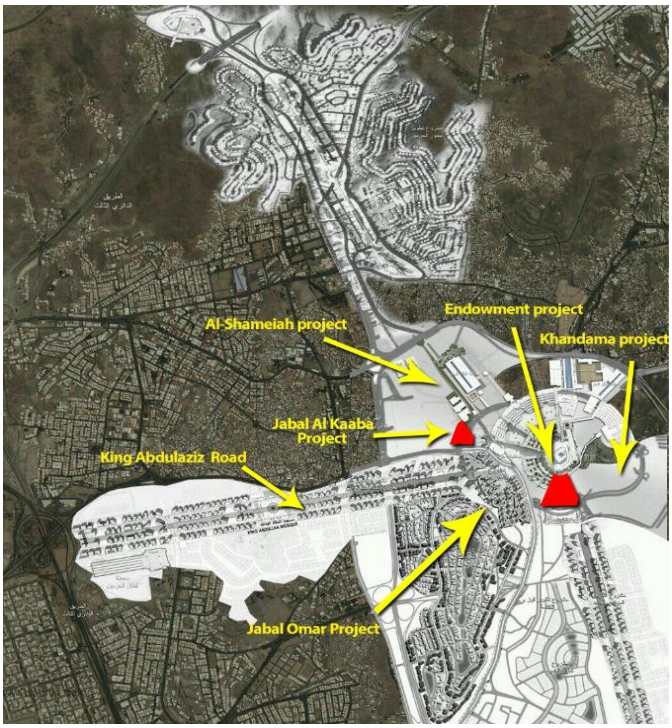

Figure 7: Urban development projects covering Makkah city

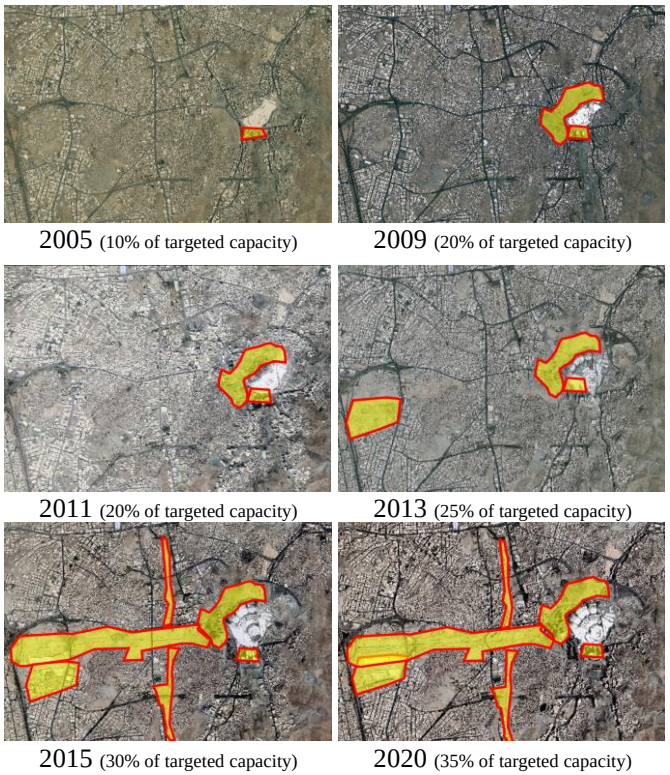

Figure 8: Time track for development projects through the last twenty years (estimated by the author)

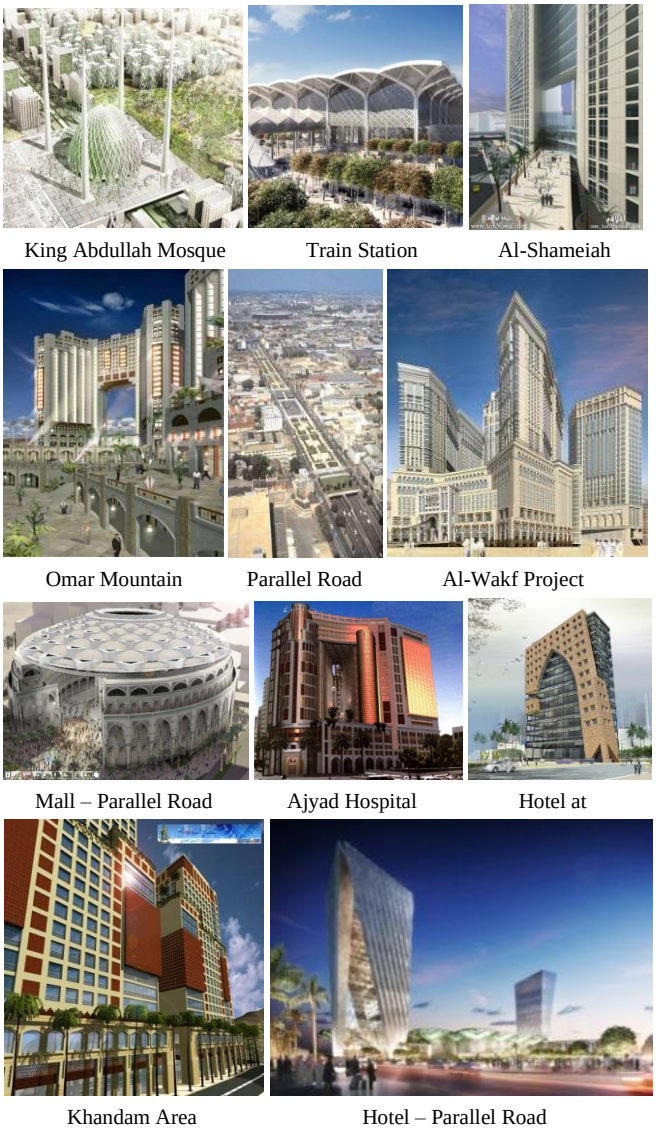

Figure 9: Architectural style of new development projects

Each of these projects has its own organizational rules in terms of elevations, setbacks, floor area ratios, capacity, urban character and architectural style. Moreover, each of these projects has its own schedule, which is governed by various elements including marketing, cash flow and business completion rates. Assuming that the time span for these projects to be completed in about 25 years, the characteristics of the center of the city are difficult to predict over such a long period. (Muhammad Muslet Al-Sharif, 2005). (Shehata A. M., 2012)

4. Data Collection:

4.1. Geo-Data Base Structure:

The old and new urban area was represented in the following feature datasets:

- **Old Area:**

DEM: (Old Levels – Excavation date)

Open spaces: (Roads – pedestrian plazas – Pedestrian paths – Demolishing Date)

Old buildings: (Heights – Areas – Capacity – Demolishing Date)

- **New projects**:

DEM: (New levels – Construction date)

Open spaces: (Roads – pedestrian plazas – Pedestrian paths – Construction Date – Operation Date)

- **New buildings:** (Heights – Areas – Capacity – Construction Date – Operation Date)

4.2. Collecting Spatial Data:

- 2D CAD polygons representing residential plots & 3D AutoCAD maps for the area were given by the city municipality, illustrated in figure 10.
- 3D Topographic map for the study area was developed by Visual Lisp subroutine.
- Development projects' initial reports including layouts, heights, architectural plans and timetables were collected from projects' management offices and consultants.
- Reports of the comprehensive and structural planning of the city by Makkah Region Development Authority.
- Quick Bird satellite image of the area with 60 cm accuracy.

4.3. Collecting temporal data:

Accommodation capacity of the urban areas before the implementation of the development projects was collected from its secondary sources. Initial timetables in addition to delays' information in terms of periods and timing. The existing situation for each urban development project within the central area of Makkah city was collected. Moreover, achieved construction progress and operational situation of the accommodation stock. These constitute the basic data for the suggested temporal model.

5. Building 3D Geodatabase

5.1. Building the Geo-Data Base:

- Digital Elevation Model (DEM) and Tin were created to represent the study area topography as shown in figure 11.
- Spatial Data representing residential plots, hotel buildings and historic buildings were created. Figure 12 shows the original urban pattern map.
- Spatial data of development projects also created.
- Spatial and descriptive data of the Makkah Grand Mosque were created.
- Existing and proposed road networks were presented and classified into categories and capacities. illustrated in figure 13.
- Descriptive data to feature datasets including phasing of the new projects.

The following information was developed by the researchers to help with assessment:

- Original urban areas Demolishing dates.
- Capacities were estimated based on floor numbers and areas of original buildings and new development buildings and the rate of square meters per pilgrim. Data of original buildings were based on field surveys by the students of the Islamic Architecture Department at Umm Al-Qura University.
- Time tables were based on development project original timetables in addition to existing progress in these projects. (ESRI, 2005).

5.2. Building the 3D Model

3D Model of original and developing projects was created using 3D analyst. Old DEM was used as a base for the elevation of old buildings and road networks. New DEM was used as the base for the new development buildings and new urban spaces. Figures 12 and 13 illustrate the old and new development 3D urban area while figure 14 presents the new 3D fully constructed new urban area.

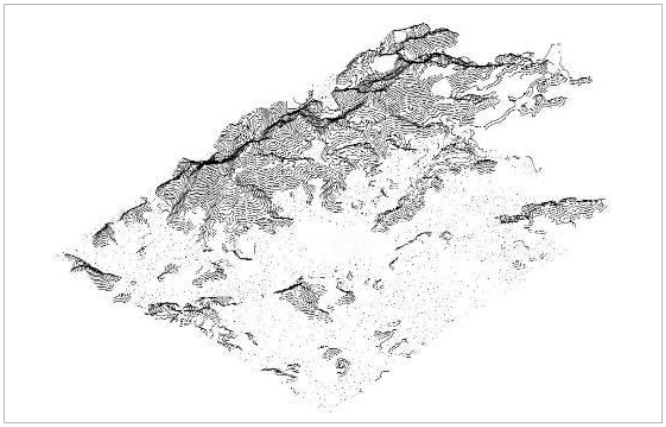

Figure 10: 3D Contour lines of study area

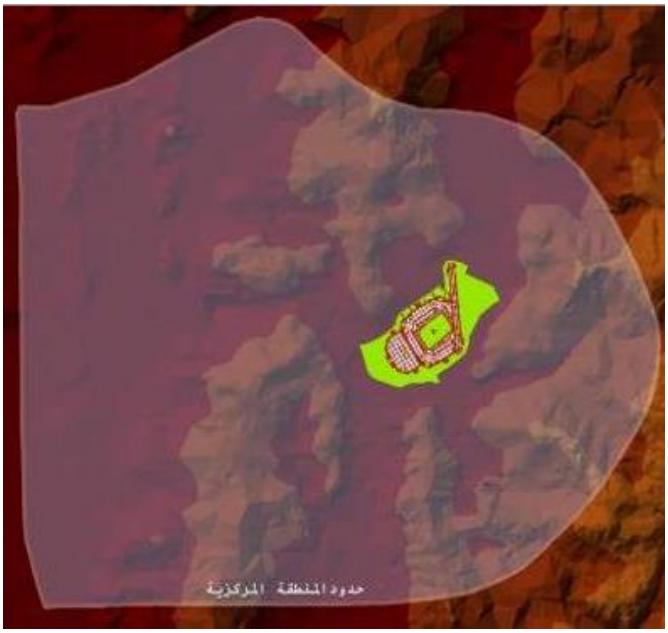

Figure 11: Topography of the study area

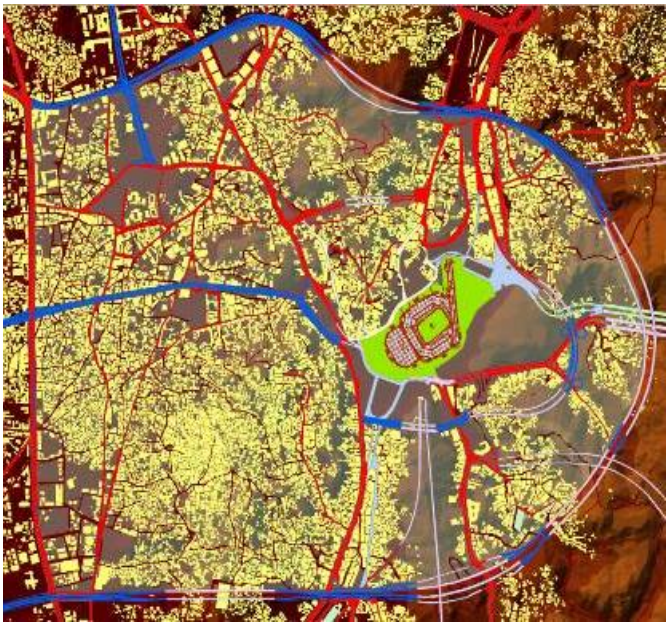

Figure 12: Original urban fabric of study area

Figure 13: Development projects spatial map

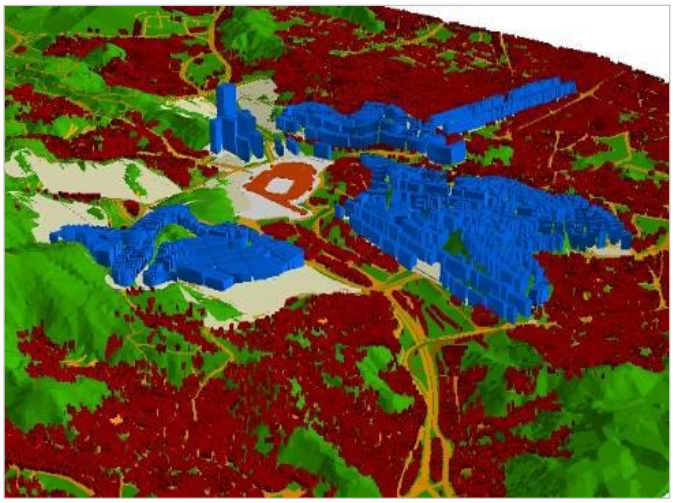

Figure 14: Shot clarifies the final visualization of the central area after development

5.3. Creating time tracking model

Using the Tracking Analyst plugin, a time track was created using the time field for feature classes of existing buildings and new development projects. Figure 14 shows the screen and the timeline of the study area development, where different and overlapping phases of the development projects within the study area are shown every three months and over 25 years (the planned development period. (CARTOGRAPHY, 2012), (Esri, 2006), (Press, 2007).

5.4. Creating tempo events:

Five-year phases were used to present the urban change over twenty-year development period as per the initial reports of the regeneration projects. The initial time tracking model was created based on the demolishing dates, projects' phases and construction timetables.

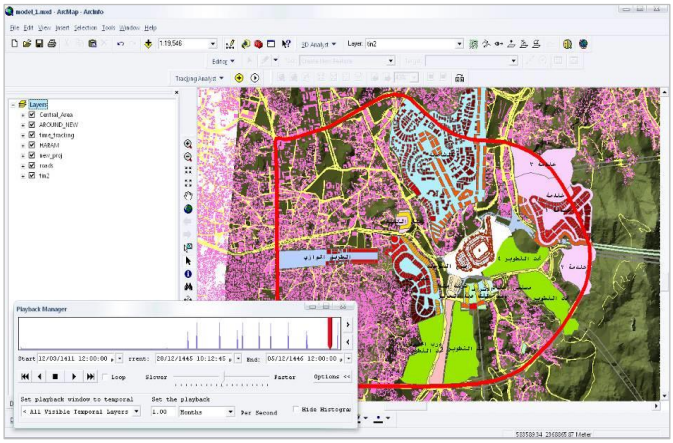

Figure 15: Tracing analyst of ArcGIS screen shot showing planned development timeline

6. Planned urban development versus existing conditions:

In 2005, all original buildings for most of the development projects were demolished on time as planned before. Al-Shameiah project was canceled due to the Grand mosque expansions and reinitiated on a smaller area. All other projects were delayed because of cashflow delays due to the global recession. Figure16 Illustrates the planned progress every five years till 2025 in five-year intervals and the existing situation of the study area. As shown in the figure, in 2010, finishing about 15% of the construction was planned but only the Endowment development project was on schedule. In 2015, 25% of the capacity of the project was planned accommodation units and services to be utilized, but only less than 10% of the estimated capacity was on schedule. In 2020, all the construction effort halted and all the reservations of the constructed units was canceled due to the pandemic.

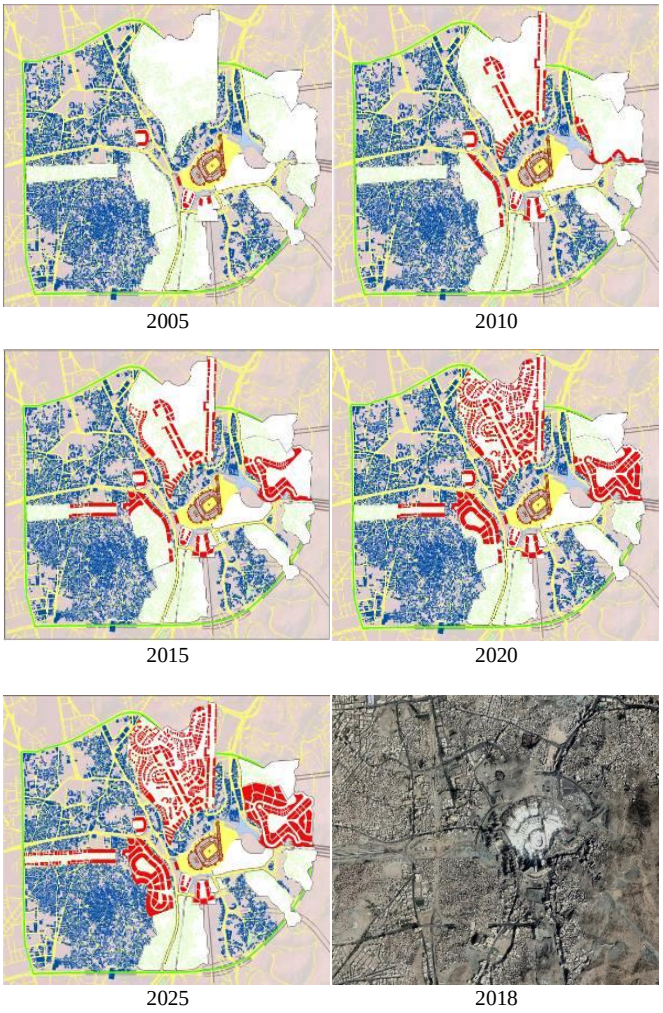

Figure 16: A collection of maps showing the urban development in the central region over the next 25 years

7. Building Temporal Model

7.1. Chronological analysis of urban dynamics

Three indicators reflect the urban characteristics and measure the development objectives. Those indicators should be monitored over the planned development period, these indicators are the total built-up area, building densities and accommodation capacity. Comparing existing urban conditions with the planned ones using the time tracking technique, it can be noticed the following points:

7.1.1. Built-up area: The chart in Figure 16 shows the change in the built-up area over the 25-year development period of the projects. Figure 15 shows Maps of the five years planned development including demolishing and reconstruction phases. As per the planned development timetable, the figure shows that, a decline in the built-up area from 1450000 m^2 to 900000 m^2 over the first seven years of development, and then gradually escalating till the end of the twenty-five years development period. The figure also shows the existing built area after 15 years that still under 150000 m^2.

7.1.2. Buildings' Density: Figure 16 illustrates the planned change in building densities within the central area over the 25 years in five years of development scale and the existing densities after fifteen years. The chart and the figures show a planned increase in the density from 3.6 to over 12 because of the new development of high rise buildings. The chart also shows in red the estimated existing is about 4 which means that the density has a very slight increase.

7.1.3. Accommodation capacity: The change in the accommodation capacity is shown in Figure 17. It illustrates the predicted change over the 25 years (development period) in the accommodation capacity. The figure shows a planned decline in the capacity during the first five years of development from 1.6 million to 850,000 person, then it begins to increase again to reach its maximum value at the end of the planned development phases. As per the existing estimations, capacity is about one million.

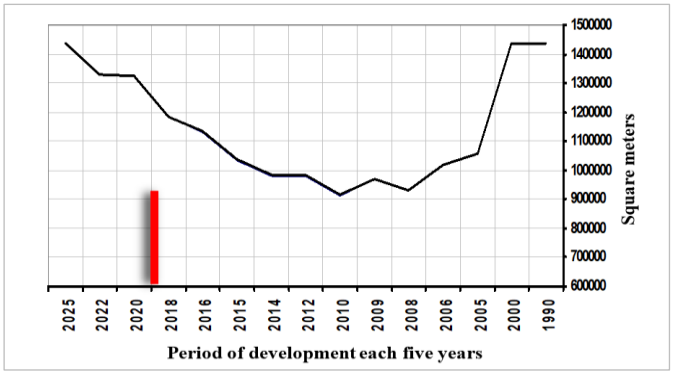

Figure 17: Planned change in the built-up area versus the existing one

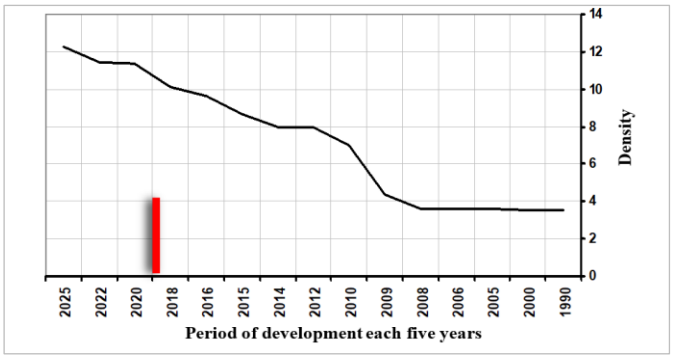

Figure 18: Planned change in building densities versus the existing one

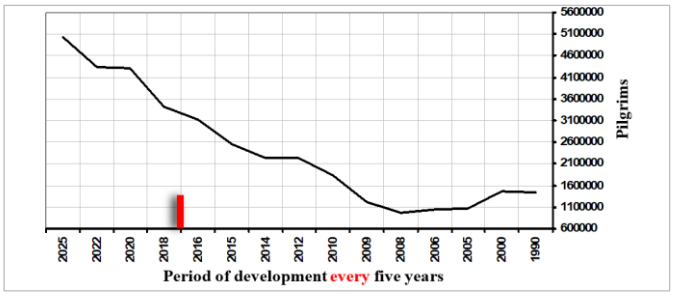

Figure 19: Planned change in accommodation capacity versus the existing one

7.1.4. Axes Linking Grand Mosque to its urban surroundings:

Worshipers arrive at the Grand Mosque from different parts of the city using various means of transportation. studies showed that the percentage of pedestrian worshipers used to be 72% of the total number of worshipers before the starting of the development projects. Figure 20 illustrates the arrival of pedestrian worshipers to the Grand Mosque from surrounding districts. White arrows present routes that are greatly reduced, yellow arrows present routs that have been canceled, while red arrows present routes that are overloaded as a result of the development. Figure 21 shows the distribution of pedestrian worshipers' percent arriving from old districts of the central area. These percentages and the numbers are changing because of the ongoing development work.

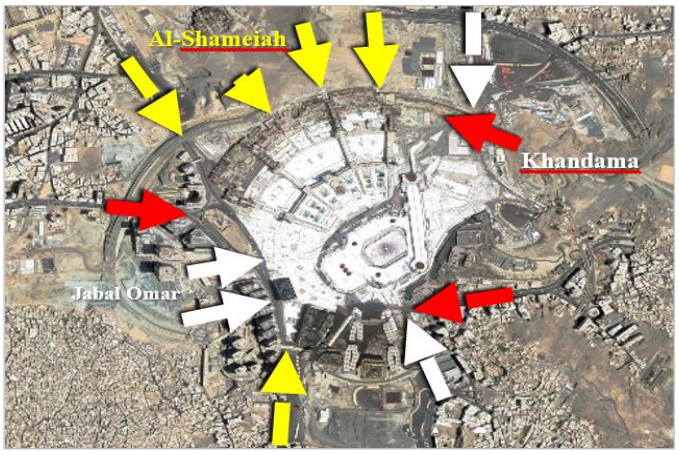

Figure 20: Impacted traditional arrival axis at the Grand Mosque

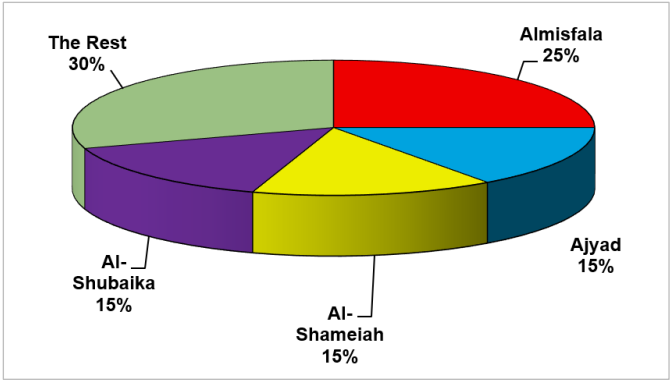

Figure 21: Pedestrian worshipers arrival directions (Shehata A. , 2007)

8. Analysis

8.1. Temporal events and their causing factors

As illustrated in figures 17, 18 and 19, built-up area, building densities and residential capacities are all lower than the planned one due to the following aspects:

- AL Shameiah project postpended due to the government decision of expanding the Grand Mosque on the front part of the area. This happened after demolishing the existing area including the hotels in 2009 the Mosque expansion still almost finished but there are no hotels or accommodation buildings within the five hundred meters next to it. New proposal to develop the area still under development.
- Jabal Omar project executed the demolishing of the existing area in 2005, then progress declined because of financial issues, changes in the partnerships of the project and the development and marketing strategies. The first phase of the project started operation in 2015. The second phase started construction in 2014 and due for operation in 2020.
- King Abdulaziz road project old area was demolished in 2010 while infrastructure started in 2012 and still under construction. The decision of building a metro line underground under the main axe of the project had been decided in 2012 this delayed the process of re-designing and construction of infrastructure which did not finish till now.
- The clock towers started in 2004 and almost completed all of its seven towers have become operational in 2014. Despite some of the services are still under development due to logistics, administrative and financial issues.

8.2. Analyzing the existing situation of study area

- The lack of coordination and cooperation between the development projects impacted the urban density, capacity, character, and fabric.
- The impact did not affect only the development area but the whole city. For instance, reducing capacity within the urban area surrounding the grand mosque put a lot of pressure on the road network and the city transportation system.
- The average new building heights and urban fabric outdoor spaces are totally changing the urban character of the historic area.
- Despite that some of the projects adopted innovative and sustainable approaches, the projects' stakeholders did not make any benefits out of the construction delay in terms of achieving new strategic objectives in modernizing their development projects.
- Despite the high land price, demolish and rebuild policies are not the best to be followed, demolishing should be phase along with the rebuild to maintain constant capacities throughout the development.
- At the end development phases, there will be lack of balance in the pedestrian flow toward the grand mosque surrounding plazas due to the change in the capacities and densities in the surrounding areas.

9. Conclusion

In this research, a temporal GIS modeling technique was developed to monitor urban dynamics. The case study of the historical area of Makkah city showed that the using the 4D model technique offered a method to identify urban changes over time in urban areas. (E. Nocerino, 2012). Research also proved that the 4D GIS technique helps in integrating different technologies that combine spatial and temporal data in one Geodatabase. This integration enriches planners' understanding of urban dynamics and aspects of changes. Moreover, it enables planners to recognize the forces influencing the change dynamics. (Barmelgy, 2019) and can be used in analyzing the impact of the different factors of change during the development processes. It also helps decision-makers to assess different alternatives and visualize the results of different scenarios. Through the study, it was proved that any modern city should be govern using a tempo-spatial GIS system to monitor, track and analyze urban conditions and any development plan outcomes, in terms of progress and factors affecting the development process. In addition to this, it would be very useful to analyze the development impact on the rest of the city. From the case study analysis, it was concluded that large and long-term development plans should be divided into sub-projects with integrated timetables. If demolishing and rebuild policies are to be followed, demolishing should be phased along with the rebuild to maintain constant capacities throughout the development. Urban development is a commercial project, it cannot be planned for 25 five years because a lot of commercial, political, and technological changes happen in such time. The case study also showed that recession would slow the progress of long-term development and Carpenter argued that certain opportunities come out of recession periods. Focusing on activities that have long-term objectives like place-making, sustainability in addition to high value-added production activities. Activities centered around innovation and a knowledge-based economy, as well as low-carbon strategies are among the long-term activities. Such activities would benefit the urban regeneration operations during the post-recession period. (Carpenter, 2011). Temporal models provide a very good tool to build on such delays offering a good opportunity for improvement and enhancement and modernizing the development outcomes.

10. Recommendations

From the previous analysis of the development projects in their process, the following can be recommended:

- Coordination and cooperation between all the project stakeholders is required under the umbrella of the planning authorities.
- Enforcing clear guidance for architectural and urban character of the development projects in the city image is going to be maintained.
- If demolishing and building is going to be followed due to the high land prices, local heritage and environment must be respected.
- GIS temp-spatial model is a very useful tool to achieve a resilient development operation.
- There is an urgent need to make detailed studies of the axes of access from the proposed projects to the Grand Mosque and their relationship to the entrances and plazas of the Grand mosque.
- The proposed geographic information model showed a significant decrease in the capacity of the central area during the first five years of development, necessitating the need to coordinate the work phases between different and simultaneous development projects.
- It's necessary to conduct a study of the relation between the Grand Mosque capacity and accessibility and the predicted large capacities of the developed surrounding projects.
- Out of the study, it is recommended to develop and build a more detailed and accurate database for more urban studies in the central area of Makkah city.

Further S**tudies:** As mentioned in the research limitations, more studies need to be done using an enhanced GIS time tracking system to monitor the urban change and help decision-makers in visualizing the expected change and assist them in taking more successful steps in easing the urban change.

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