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## Research Article:

### Irregular Growth Patterns In The Case Of Mosul's Urban Structure

No'man M.H. Bayaty<sup>1,a,\*</sup>  
Omar Al- Shammai<sup>2,b</sup>  
Azad Ahmad Yasien Barzanchi<sup>3,a</sup>

<sup>a</sup> Department of Architectural Engineering, Tishk International University, Erbil, Iraq

<sup>b</sup> Ministry of Youth and Sports, Iraq

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##### About the Authors:

**Corresponding author:**  
E-mail: [noman.bayaty@tiu.edu.iq](mailto:noman.bayaty@tiu.edu.iq)

##### Researcher Involved:

Omar Al- Shammai  
Azad Ahmad Yasien Barzanchi

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#### Abstract

Mosul, the second most populated city in Iraq, has been growing irregularly for almost two decades. The pattern of this sprawl shows imbalance in the city's growth. The study mostly focusing on the urban structure of the city, includes indicators of social, economic, and political irregularities. This study used a mixed-method approach to reach its findings, by applying more than a test. The study aims to check how this irregularity is taking place in Mosul, by studying the geographical and the syntactic models. The study is an analytical one and has a descriptive aim. It checked the indicators of imbalanced growth by observing the city's growth through three decades. Satellite images were used to observe the growth, and then a field survey of the distribution of the most important elements (such as schools and hospitals) was conducted. Educational and healthcare facilities represent the most important infrastructure needed for any city to grow, and their distribution patterns can show if the growth patterns of a city are regular or not. Axial segment analysis, part of Space Syntax analyses, was also used to check the integration values of the local cores in the city and how they changed through time. The results show clear indicators of unbalanced growth and distribution of facilities across the city. The results also indicate irregularity in the city's growth through the last three decades. The study shows that the Eastern bank of the city is growing three times faster than the western bank, and that the Eastern bank has 1.5 to 2 times more health and education infrastructure. Space Syntax showed that the values of integration for the local cores are becoming weaker as the city is expanding. The maps produced by the study can prove useful for any party trying to develop a new masterplan for the city.

## 1. Introduction

Urban sprawl and growth patterns are affected by dozens of factors. The growth of cities can be directed in specific desired directions, depending on the cultural, political, and the natural context. Mosul, a city divided by a river, has grown along the two sides, having an eastern bank and a western one. Since its

early erection as an Assyrian capital the city moved between the two banks. The Assyrian city was situated on the eastern bank, even though some studies claim that the oldest castles were on the western bank. After the Islamic conquests, almost a new city emerged on the western bank. Until the 20th century, Mosul was a walled city on the western bank, with the grand Nouri Mosque in the center. The eastern side of the city was

mostly small settlements scattered on a large area, with no strong urban center.

In the 21st century, the city witnessed a large expansion, like the other cities in the country and in the middle east. And till the 1970s the majority of the city's commercial areas, and governmental institutions were on the western bank. According to a study conducted in 2011, on the city's commercial streets, it is noticed that the streets that were officially classified commercial by the municipality, were more concentrated on the western bank than the eastern, taken the difference in area into account, and they covered more are on the western bank than the eastern. [Al-Sabaawi and Al-Hadidi: 2011]. After 2003, the governmental and political conditions changed drastically and today the city is growing without a clear vision or a masterplan. This research tries to observe some of the aspects that appear and indicate a city's growth.

Space Syntax, on the other hand is a set of theories and analytical techniques for modeling and analyzing spatial configurations, particularly in buildings and cities, to understand how spatial arrangement influences human behavior and social organization [Bafna: 2003]. Developed in the 1970s by Bill Hillier and his colleagues, it treats space as a fundamental generator of urban and architectural systems, and it focuses on the relationships between spatial configuration and urban functions, movement, and social interaction [Karimi: 2018]. It has been used heavily to analyze urban systems and predict any problems that might appear within it. The study will focus on three aspects of studying the urban condition of Mosul. First aspect is focusing on the way the landmass is added through time. Second by studying some elements of its infrastructure and how they are distributed. The third by studying Space Syntax and its applications in measuring the urban growth.

## 2. Previous Studies

There are number of studies that tried to tackle the urban growth of cities from different points of view. (Li and Gong) presented a survey of the models used to study urban growth. Their study gives three main models that can define the process of urban growth; Models based on land use and transportation, agent-based models, and cellular automata-based models [Li and Gong: 2016]. (Makse, Havlin and & Stanley), tried to study the urban growth from a morphological point of view, by predicting, mathematically, how the urban fabric of cities can expand [Makse, Havlin, and Stanley: 1995]. (Duranton and Turner), studied the urban growth and its association with the development of the transportation networks, in American cities, and found a rise in employment rate with the increase of city's stock of highways [Duranton and Turner: 2012]. This study will focus on two types of research in this

field. The first is focusing on the geographical and the distributional nature of certain elements in the city. One research tried to study the distribution of medical clinics and pharmacies in Mosul. It compared the locations and the distribution of clinics with the pharmacies and discovered a tendency of both being close to each other and to the residents of the doctors [Odu: 2011]. Another research tried to study the locations of the primary schools in Mosul, and then tested the coverage area of each school, within the walking distance of children (400 meters). It showed that almost half of the city's neighborhoods don't provide schools within the 400 meters range, and 75% of them were within the 800 meters range [Ahmad: 2021]. A similar study was conducted by comparing the locations of hospitals, to the integration and choice cores, but for Erbil, a different city [Bayaty: 2020]. A study published in 2019, used both descriptive and analytical tools to study the distribution of services such as hospitals and schools on urban and population growth on (Al-Salt) in Saudi Arabia from (1994) to (2015). The study showed that these services are strong indicators of urban growth, and when not matching the population growth, cause overcrowding, weaker accessibility, increased travel time, and poor quality of these services [Samha & Al-Washah: 2019]. Several other studies evaluate or analyze the urban condition through the distribution of health care facilities or educational ones. Research published in (2024) studied the relationship between shrinkage of cities and how it can affect health care inequity [Wang et al.: 2024], which is something the current study also trying to show. Another research focused on the change in urban and population growth and how it may affect their accessibility to health services. The study presented its findings by studying the transportation systems to achieve less travel-times in a Canadian city [Mayaud et al.: 2018]. A third study presented evidence that urban sprawl and growth of cities can lead to inequality, and again the study showed this through studying the locations and distribution of hospitals in Beijing [Li, Liu & Zhao: 2020]. One study used GIS techniques to check the distribution of hospitals and hospital beds in 5 Iranian cities and pointed out to the urban problems associated with irregular distribution, and how it is associated with rapid urban growth; something every city planner should keep as a priority to solve [Takian et al.: 2019].(Tian et al.) shed light on urban expansion and the distribution of basic education schools in Shanghai. The study used several statistical methods to show how an unequal distribution of schools is an indicator of irregular distribution and growth [Tian et al.: 2021]. Another study also in China, analyzed the distribution of schools and how it is affected by certain urban transportation elements like bridges and tunnels. These elements change the levels of accessibility, and the

study emphasizes that an unequal distribution of schools and educational access is an important factor to be studied [Mo: 2023].

Space Syntax, a second method of analysis used by current research, on the other hand has been used extensively as a tool to measure urban characteristics. It has been one of the essential urban analysis tools for urban studies since the 1990s. (Xia et al) used Space Syntax to study urban growth. They focused on segment analysis and applied the analysis on different periods on a town and studied the expansion of urban boundaries. Results of segment analysis were compared to remote sensing images, and a regression model was proposed. The study showed that when the model was used to predict the expansion of the actual boundaries, it was feasible, and the simulation was close to the real application [Xia et al.: 2019].

Space Syntax is a strong analytical tool to study urban growth, through different measures. A study published in (2024) attempted to use Space Syntax to analyze urban areas in Malatya in Turkey. The analysis used various radii to check the settlement's readability and accessibility at several scales, and found that values of readability were decreasing, which requires attention from the planners [Selcuk & Gunaydin: 2024]. Another study also published in (2024) studied the Italian city of Pisa, and again used the multi-scale nature of Space Syntax. This time the authors tried to use this method to investigate the capability of Space Syntax to estimate pedestrian and vehicular flows and how it correlates with the distribution of commercial activities, at large and small scales. The study underscores the potentials of the Space Syntax and its multiscale approach for analyzing urban settlements [Deri et al.: 2024].

Another research tried to study historical urban centers at different historical stages, something similar to the current research. However, the tools used were different. It focused on using Space Syntax along with GIS techniques to study urban morphology and the evolution of Famagusta in Cyprus through different historical eras [Allahmoradi & Atakara: 2021]. A research published in (2020), proved that Space Syntax is a strong and effective tool to study the levels of urbanism, and to also predict the urbanity of a settlement in the future. This was done by studying Al-Damiatta in Egypt and analyzing its urban condition [Samra, Eleishi & Eldiasty: 2020].

Space Syntax is used along various other entities, concepts, and aspects of urban settlements. Along with GIS, cognitive aspects, transportation systems, and other economic structure of cities, Space Syntax can be a powerful tool to analyze an urban structure and bring out its deep syntactic issues.

To conclude this section, two types of studies were surveyed, and each one will benefit the research in a different way. First, studies show that the distribution

patterns of infrastructural entities (hospitals and schools specifically for this study) can be a clear way to predict problems in cities. Bad distribution patterns can lead to inequity and less social justice. Studying the patterns of distribution of these institutions, have proved, according to several previous studies, that they can be an important part of studying the growth of any city in the world. Some studies even suggest that a good & smart planning and equal management and distribution of education and healthcare across cities can lead to enhanced life expectancy [Zhang, Zhan & Chen: 2024]. Second, Space Syntax is a versatile methodology which intersects with several other analytical tool to study urban forms. The previous studies showed this versatility, but the current research is going to focus on Space Syntax itself, as an independent tool for analysis. Space Syntax can analyze urban forms at several radii, to find the local and global cores of the urban system, like some of the previous research papers. Space Syntax is a powerful tool, not only to analyze, but also to predict any future problems.

### 3. Research Methodology and Aims

As presented in the previous studies, urban growth has been measured through different models. Our research is an analytical one, so its aim is to discover rather than justify, find rather than prove or disprove. The research aims to show indicators of the imbalance in the city's growth. The research tries to shed light on the levels of inequity that seem to take place in the planning of the city, and to show how this inequity is happening and on which scale, especially between the two banks of the city, which are separated by Tigris. The research aims to analyze the city's fabric and find irregularities in its structure. These aims are going to be achieved by creating a series of maps, and by going through a mixed-method analysis approach. This will be achieved by doing three different tests, descriptive, statistical, and analytical in their nature. First the research will study the city's urban mass in three stages. The first stage is the city in the 1990s decade. The second is the city in the first decade of the 21st century, and finally the third stage is the city in the end of the 2010s. The research will calculate the urban mass in each period and how it is being added across the two banks of the city. Second, the research will point down the most important elements of a city's urban fabric and their distribution across the city's fabric and check the equality of this distribution. The study will conduct a survey counting the private schools and private hospitals and medical centers around the city. These institutions are private, and the city's residents have the freedom of choosing their locations. That is why their locations can be more honest, in showing the tendency of social and economic growth of the city. Third, some aspects of

this growth can be studied through the syntactical studies. Since the earliest studies that proposed the theory [Hillier and Hanson: 1989], Space Syntax has developed into an advance methodology that studies different urban phenomena. The various types of analyses it presents, depend on different representation models, one of them is segment analysis [Xia: 2013]. In this study the segment analysis is used to study the syntactical measures in the first stage of the city (1990s) and the second stage (end of 2010s) and check the differences in these measurements. The software used is DepthmapX, and with the analysis the local cores will be discovered and then the values of integration (definition can be seen in [Al Sayed et al.: 2014]) between the three periods will be compared. Our research will conduct the Axial analysis on the three different stages, explained earlier, and at different radii. This will show us how the integration cores are changing and check their values to reach an understanding of how the city is growing, syntactically. The structure of the study can be seen in Fig (2). The study aims to show indicators of the irregular growth that the city is going through. It is growing almost without a masterplan, and this study will try to present information and charts that specify the irregularities, with numbers and maps.

#### 4. Discussing The Results

##### 4.1. City's Growth

It is seen from the following figures how the city has grown. Fig. 3 shows the city's urban fabric in the first stage (1990s-decade), fig. 4 shows the city in the second stage (2000s), and fig. 5 shows the city in the third stage (2010s). These satellite images were translated into the maps shown in Figures, which show the city's fabric in the same consecutive decades.

When these three stages are put in a single map, shown in fig. 6, we can determine the urban masses added to the city throughout the three stages. In the first stage the city's area was around 92 sq.km. The area of the eastern side of the city had a land mass area of 57 sq.km, while the western bank had an area of 35 sq.km. This shows that in the last decade of the 20th century the eastern bank already larger than the western bank. In the second stage, in the middle of the first decade of the current century, the city added around 46 sq.km of land area. The eastern side had three quarters of it, by adding around 35 sq.km of built-up area in the eastern side, and the western part of the city added around 11 sq.km. In only ten years, the eastern bank of the city, added built up urban areas, equal to the entire western bank's area of a decade ago. In the third stage, the city's urban fabric expanded by almost the same ratio. The eastern bank added 34 sq.km, while the western bank added around 10 sq.km, with a total of 44 sq.km. It is clear that the eastern part of the city has been growing at a much faster speed than the western one.

For the last 20 years, the eastern side is adding three times more area to its fabric than the western side. From the legal point of view, the land ownership regulations are the same, but more expansion on one side against the other, shows a strong desire from the population to own private lands and houses on the eastern side than the western.

##### 4.2. Distribution of Private Services

One of surveys conducted was counting the private medical and educational institutions. The city has 56 private schools in total, 44 in the eastern bank and 12 schools in the western bank. This indicates a very clear difference in distribution between the two parts of the city (shown in fig. 7). Even when the difference in areas is taken into account the results stay different. There is one private school for every 2.9 sq.km in the Eastern bank and one school for every 4.6 sq.km in the West. It seems like there is a strong desire by investors to open private educational facilities in the eastern part of the city. This also reflects the locations and neighborhoods from which students usually come. The differences in social classes in terms of the education level, and the economic capabilities of families is also reflected in this chart. The chart indicates that the families living on the eastern side of the city have a higher educational level and stronger financial capabilities.

Almost the same can be shown in this other chart (fig. 8), that shows the distribution of private hospitals and medical centers in the city. The city has 37 private hospitals and medical centers. 6 of these institutions are located on the western bank, and the rest, 31 centers are located in the eastern part. Again, by taking the difference in areas into account, it is realized that eastern bank of the city has one private health institute every 4.1 sq.km, while the western bank has one at every 9.3 sq.km, which is half of the previous figure. Private health institutions require a higher financial income since these services are not cheap in comparison to the average income of the Mosulian family. The concentration of these centers in specific parts is transforming certain streets to entirely medical purposes, such as (Al-Masarif) and (Al-Malia).

##### 4.3. Space Syntax Analysis

The study conducted a segment analysis, with the metric radius. The analysis was conducted at 250m radius, 500m, 1000m and the global (N) radius. Smaller radii expose the local cores in the system. The 250m and 500m radius show the local cores at (5-10) minutes walking distance. The 1000m radius show the cores at larger distances (20 minutes' walk or 5 minutes by car), while the (N) radius exposes the global cores in the system. Fig. 9 shows the segment integration map at 250m radius for the first stage of the

city's plan, while fig. 10 shows the same map for the second stage and fig. 11 shows the 250m integration map in the third stage. Usually, the highest 10% of the values are taken to specify the integration core. The value of the average of 10% highest integrated spaces in the first stage at 250m radius was 102.582, while in the second stage it was 85.4 and the third stage was 72.1. The local cores, at the same radius, have lower values as the city expanded. At 500m radius the results are almost equal (as shown in fig. 12, 13 and 14), with 128.6 at the first stage, 130.08 at the second stage and 128.7 in the third. At 1000m radius again the values integration become lower as the system increased in size (shown in fig. 15, 16 and 17), with 340.8 in the first stage, 319.6 in the second stage, and 315.1 in the third. When global cores are checked at N radius, the values increase as the system expands, with an average of 5288.3 in the first stage, 7597 in the second, and 9710 in the third (shown in fig. 18, 19 and 20). The large difference can be explained easily. Since the first stage had less spaces, it would by result, have lower values. If the average of integration values is divided by the number of spaces, to neutralize the size of the system, the results will again acquire the same previous inclination. The number of segments in the first stage was 23115 spaces, and in the second stage 35408 spaces and in the third 49189 spaces. The normalized values, if it is possible to use the term, of the N radius integration will become, 0.2308 in the first stage, 0.2199 in the second stage, and 0.2040 in the third stage. Again, the integration values decrease as the city grows in area.

We can see the inclination in fig. 21, and how the values of the averages of the integration cores in the three decades get lower. To strengthen the results, the average of the 100 highest values of spaces in each analysis were taken and compared with each other. The average of the 100 highest values of integration, at 250m radius in the first stage was 164.2, in the second stage 158.3, and in the third 128.6. At the 500m radius the results have a weak inclination oppositely, with 139.2 in the first stage, 149.5 in the second, and 144.6 in the third. The 1000m radius goes back to the lower inclination, with 392.03 in the first stage, 371.6 in the second, and 366.3 in the third. With the global N radius, the same results appear. The average of the values gets higher because of the large number of the spaces (5336, 7787, and 10035 for the first, second and third stage respectfully), and by dividing them by the number of spaces, the exact previous result will appear. The inclination of these values can be seen in fig. 22.

When the values of these local integration cores were checked individually something else was noticed. Some of the local cores, that appeared in the first stage of the city, continued to be local cores when the city expanded. When their values were checked, it turned

out that they have not changed at all. Randomly, some of these spaces were picked, and their values were compared between the three phases, and it turned out, they were exactly the same. This means that the reduction in the average of the 10% highest integration values, was resulted from the new local cores that appeared throughout the city as it expanded. In general, if the number of spaces is the same within the same radius, and with similar connections, then the averages should also be the same, but that was not the case. It is difficult to interpret these results into clear conclusions, without taking other factors into account. When a system expands and new spaces are added, the global values of integration increase (which happened in this case), but the way local cores' values decreased require more investigation. Lower values of integration mean, lower amount of movement towards the space, and less crowding.

## 5. Conclusions

Mosul, the second largest city in Iraq, has been growing without a clear vision for almost 2 decades. In the previous sections, some indicators of this irregular growth were shown. In terms of area, the two banks of the city are growing at different speeds (eastern bank is adding three times more area than the western bank). In terms of distribution of private facilities, again the imbalance shows in the ratios of distribution, which indicates an irregular distribution of economic power and educational status in the city.

Space Syntax also had some irregular results, by showing lower integration values for the local cores along the city's expansion. These findings can lead to very strong conclusions, that the Eastern bank of the city is growing faster and with much more economic attention. Educational and health services are spreading much more and a faster pace, while the western bank of the city is receiving much less attention. The landmass added on the Eastern bank is 3 times more and the services are added almost by double (for every single school and a single health center/ in the western bank there are almost 1.5 or 2 in the eastern bank, that is after taking the difference in area into account). Most of the expansion is taking place along Erbil axis, and Duhok axis, while Kirkuk and Baghdad axes are growing much slower. Space Syntax's result are also difficult to interpret with a single research, but in general the integration cores were getting weaker as the city grew. Maybe the addition of new centers across the city's expansion is causing this, or maybe it is a general attitude for cities across the world. Overall, these results need to be strengthened by further research, into other cities, with similar and different sprawl conditions, to check whether the same case occurs or not. The study tried to provide data, numerical or visual, to any party, who tries to update the city's masterplan in the future.

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## أنساق النمو غير المنتظمة في الهيكل الحضري لمدينة الموصل

### المستخلص

الموصل، ثاني أكبر مدن العراق من ناحية التعداد السكاني، تنمو بشكل غير منتظم لعقدين تقريباً. نسق هذا التمدد الحضري يظهر عدم توازن في نمو المدينة. الدراسة هذه تركز بصورة عامة على الهيكل الحضري للمدينة، وتدل على مؤشرات عدم انتظام من النواحي الاقتصادية والاجتماعية والسياسية. دور الحكومة قد يكون عاملاً يزيد من عدم التوازن في النمو، إما من خلال عدم تقنين مخطط أساس كفوء، أو من خلال إهمال المشاكل الحضرية. الدراسة نظرت في مؤشرات عدم التوازن من خلال مراقبة نمو المدينة خلال ثلاثة عقود. تم استخدام الصور الجوية لمراقبة النمو، ثم تم إجراء مسح لتوزيع العناصر الحضرية المهمة (كالمؤسسات التعليمية والصحية). تم أيضاً إجراء تحليل القطع المحورية، وهي جزء من تحليلات قواعد تركيب الفضاء، وتمت دراسة قيم التكامل للأبنية المحلية للمدينة وكيفية تغيرها خلال العقود الثلاثة. النتائج تظهر مؤشرات على نمو غير منتظم وتوزيع غير متوازن للفعاليات حول المدينة، وتظهر كذلك عدم انتظام نمو المدينة خلال العقود الثلاثة الأخيرة. المخططات التي تم انتاجها من قبل الدراسة قد تكون نافعة لأي جهة تحاول تطوير مخطط أساس جديد للمدينة في المستقبل.

### الكلمات المفتاحية:

النمو الحضري؛ أنساق النمو؛ الموصل؛ قواعد تركيب الفضاء

Tables and Graphs and pictures

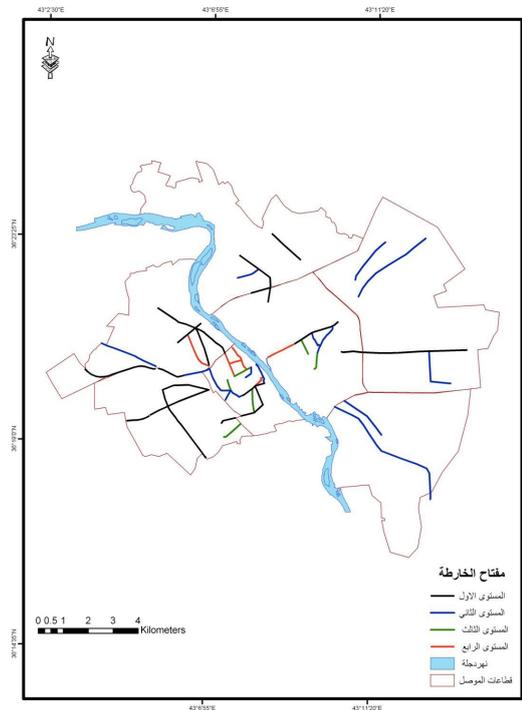


Fig 1: *The commercial streets of the Mosul till the year 2007* [Al-Sabaawi and Al-Hadidi: 2011: p. 377]

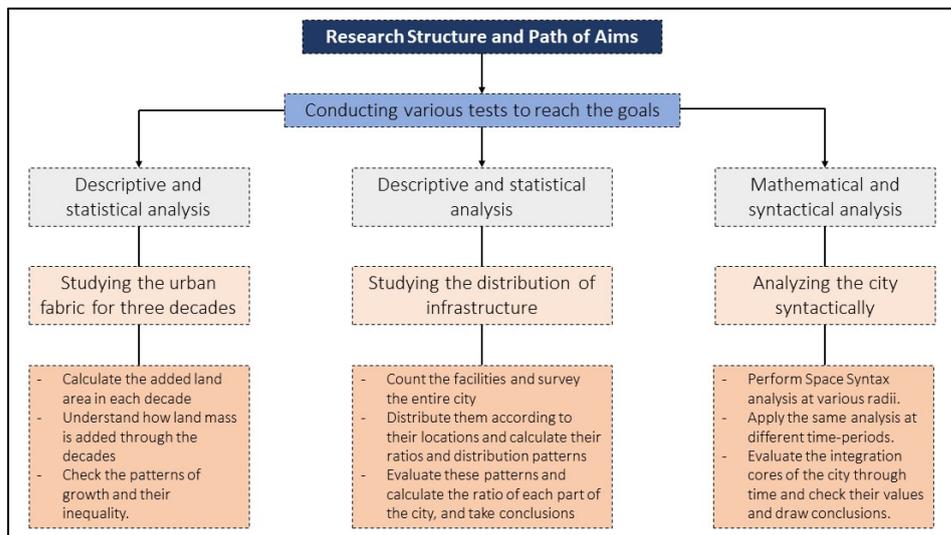


Fig 2: *The structure of the study* [Researcher]



Fig. 3: Mosul's urban fabric in the first stage [Researcher]

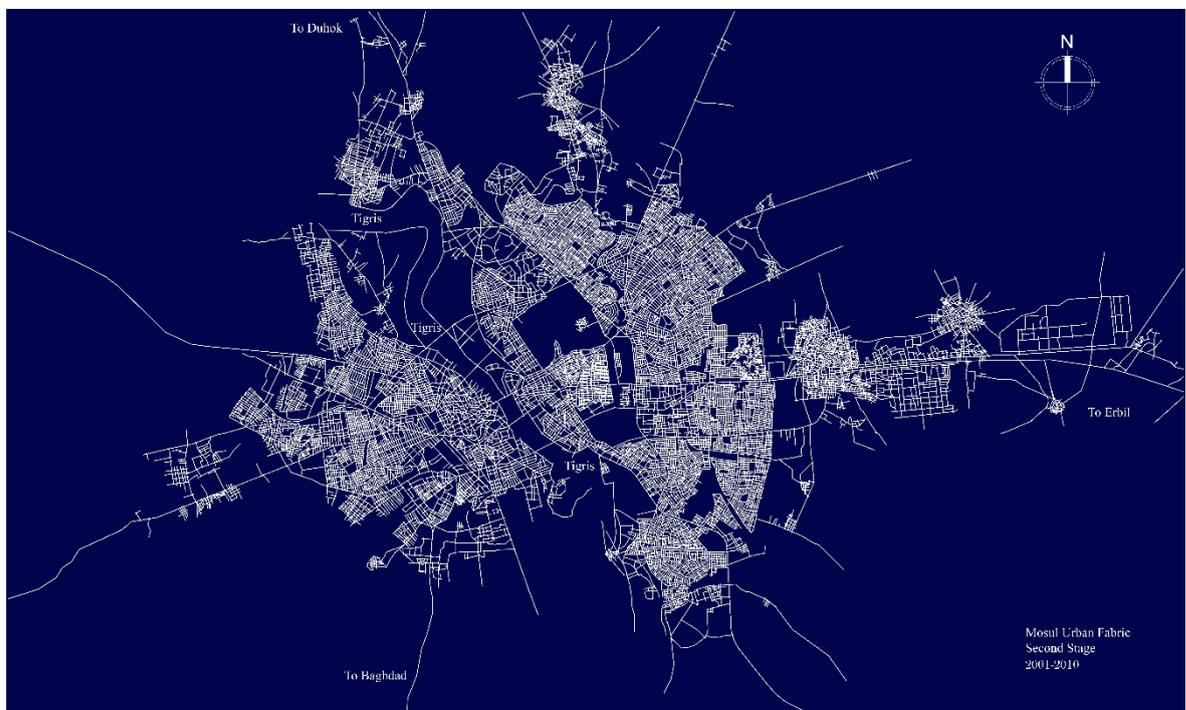


Fig. 4: Mosul's urban fabric in the second stage [Researcher]

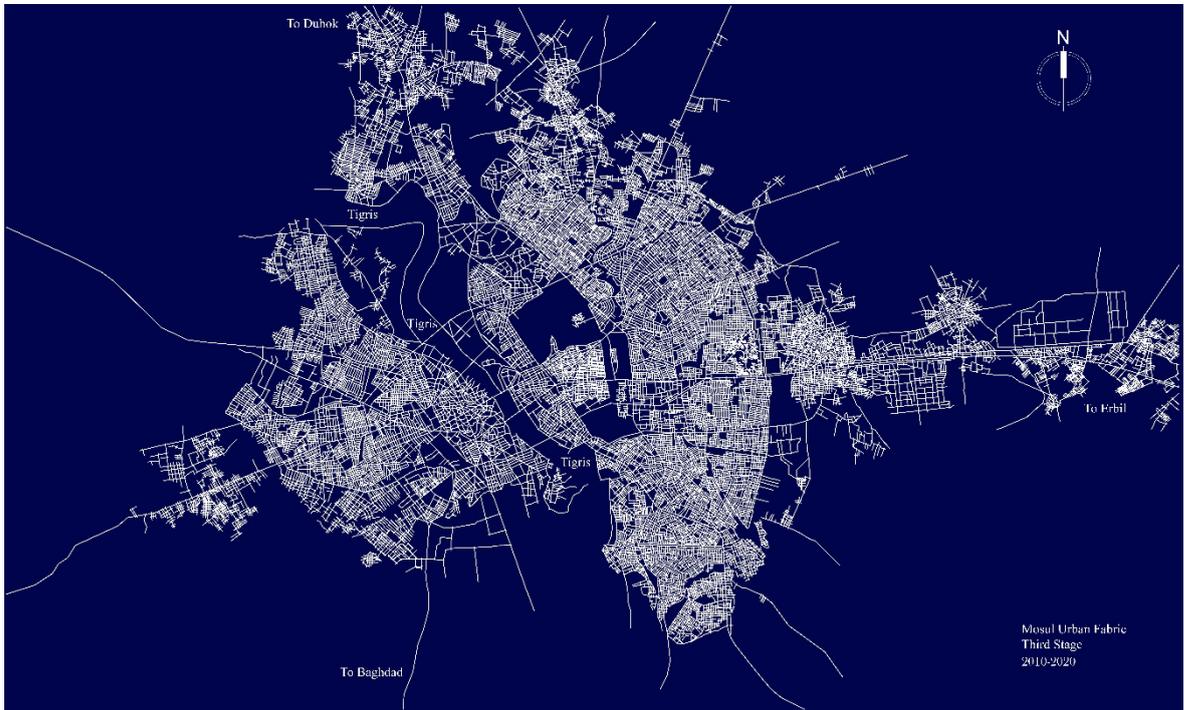


Fig. 5: Mosul's urban fabric in the third stage [Researcher]

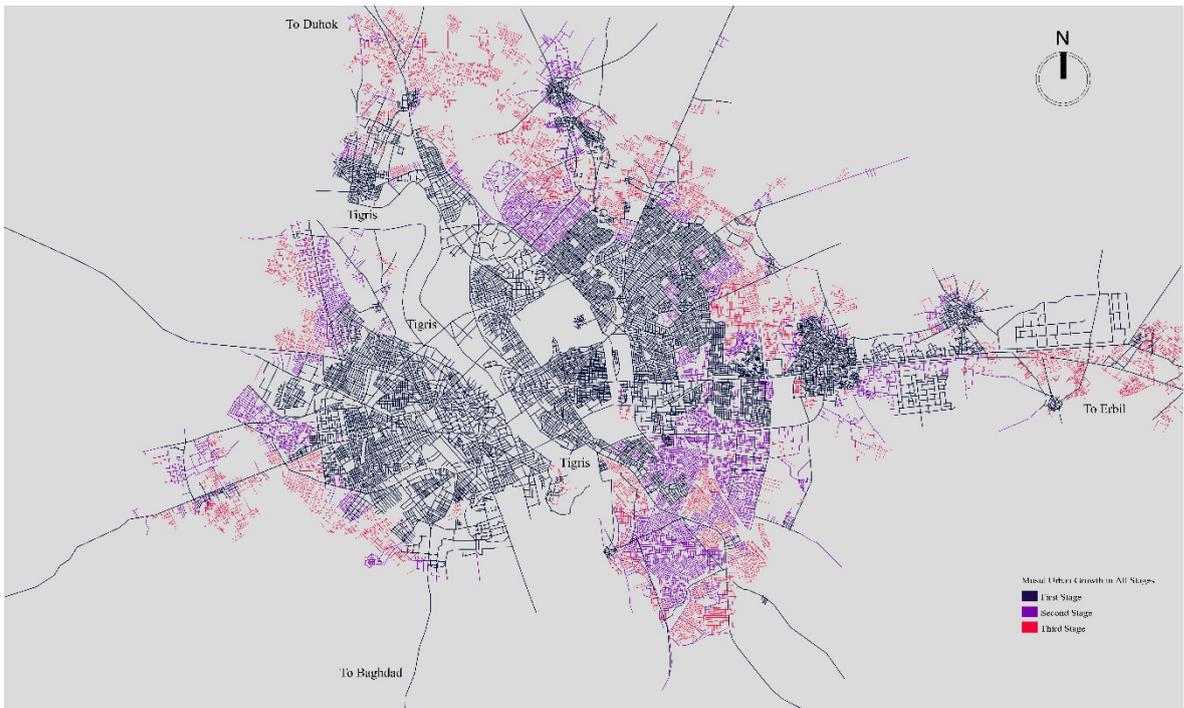


Fig. 6: Mosul's urban fabric in the three stages, black represents the first decade, purple the second and red the third [Researcher]



Fig. 7: Private schools' distribution across the city, each dot represents one school [Researcher]

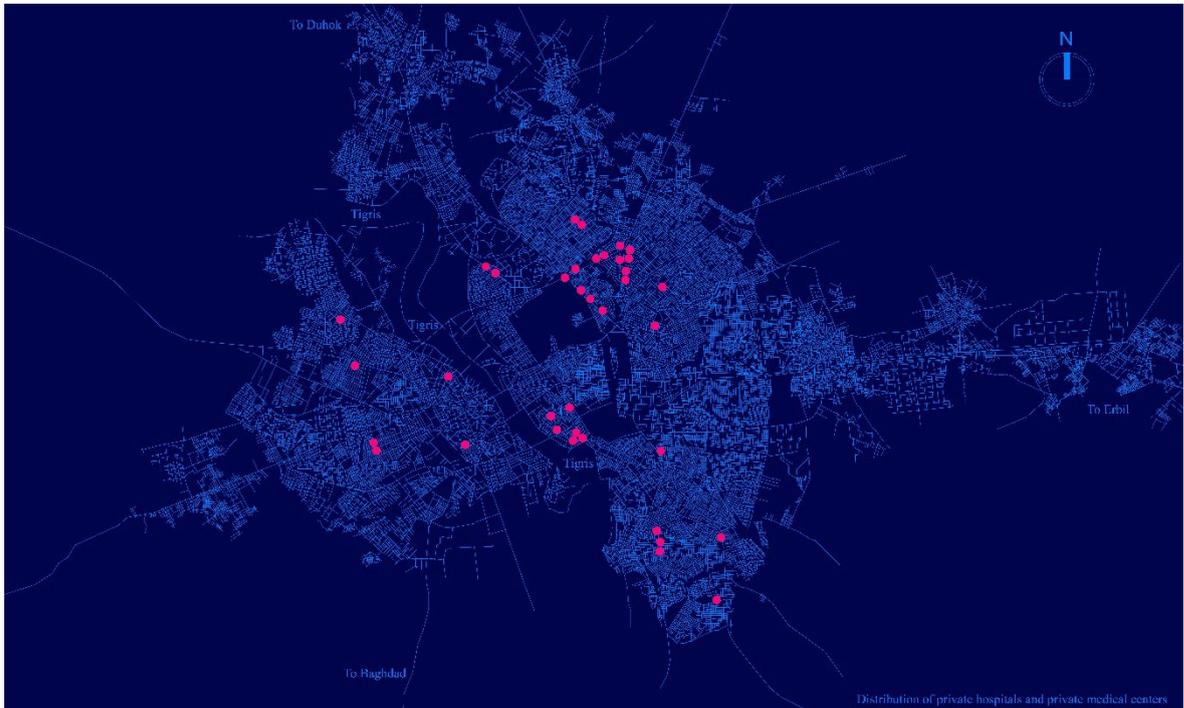


Fig. 8: Private health institutions' distribution across the city, each dot represents one institution [Researcher]

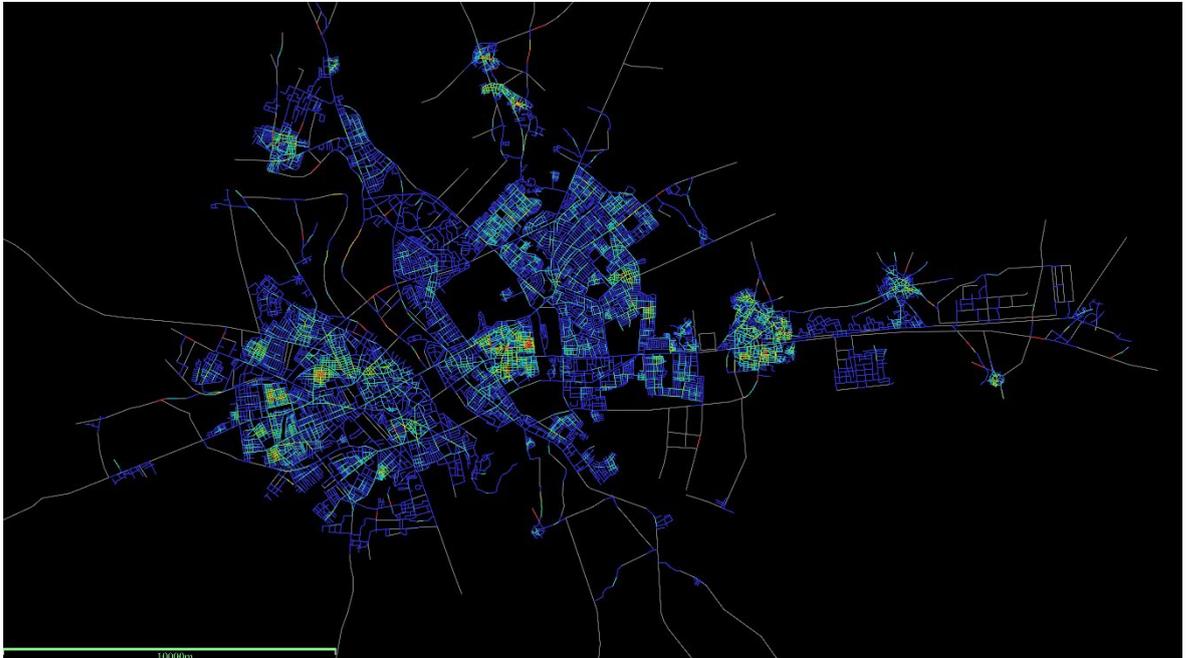


Fig. 9: *Integration cores of Mosul at 250m radius, the first decade* [Researcher]

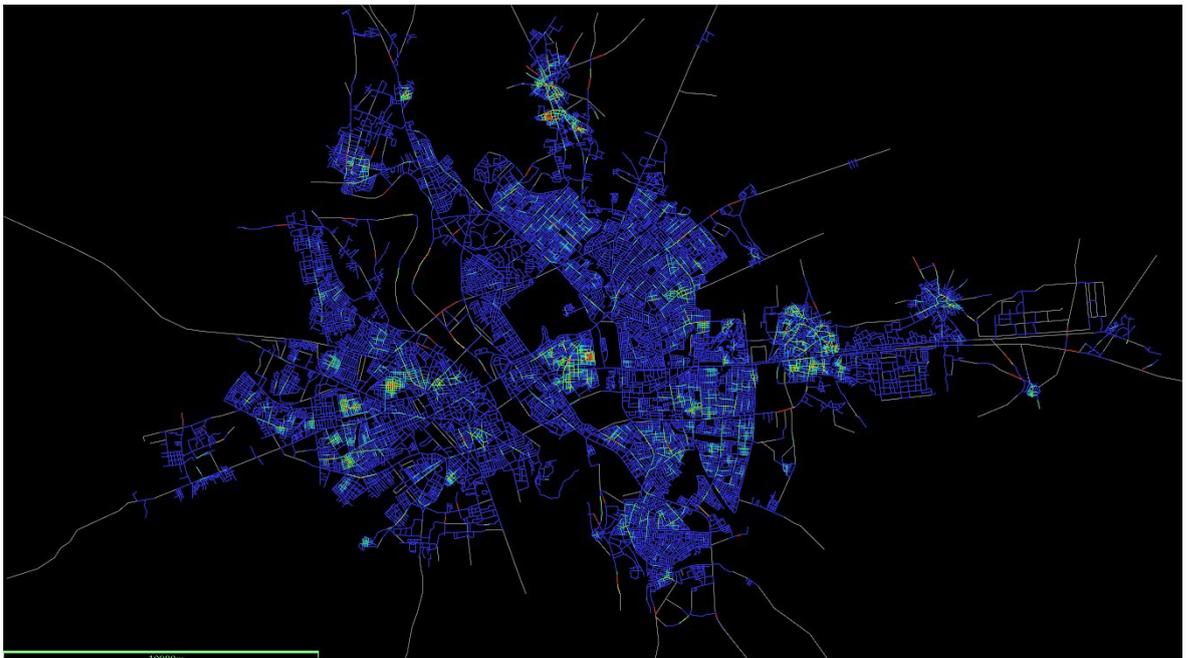


Fig. 10: *Integration cores of Mosul at 250m radius, the second decade* [Researcher]

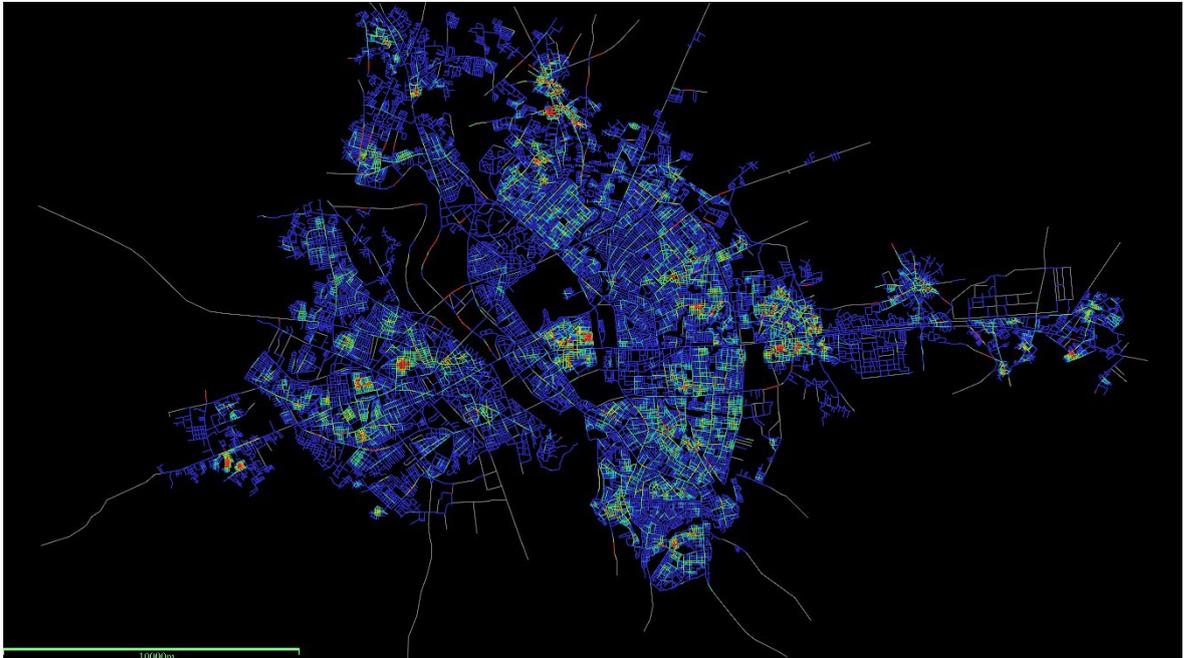


Fig. 11: *Integration cores of Mosul at 250m radius, the third decade* [Researcher]

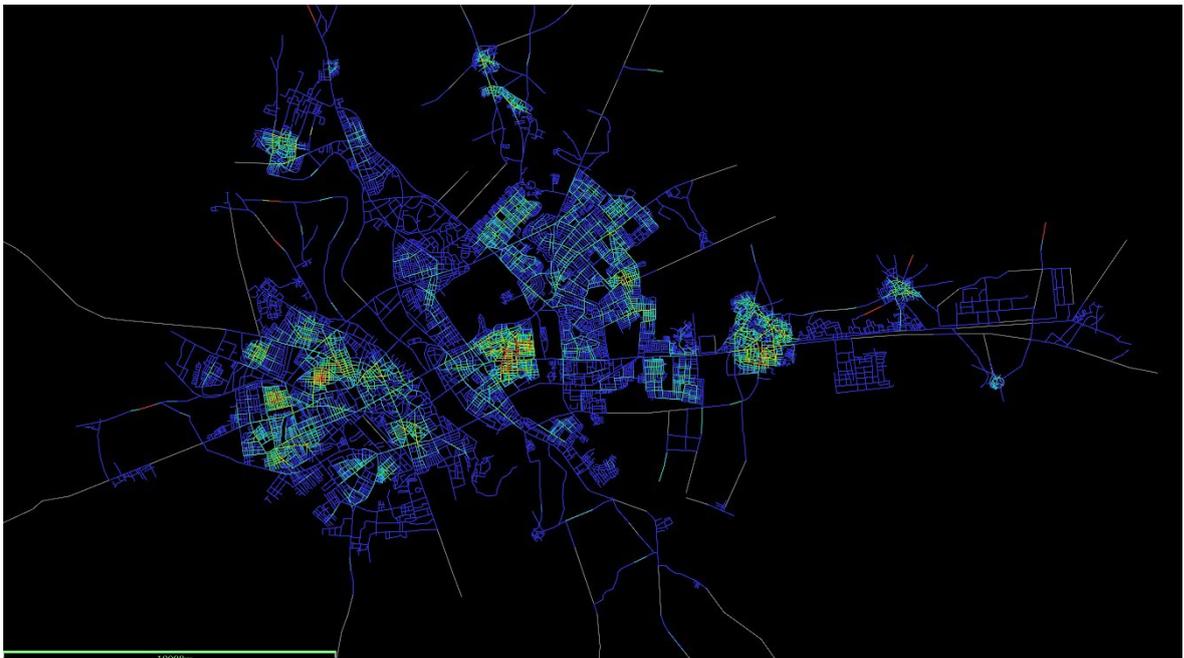


Fig. 12: *Integration cores of Mosul at 500m radius, the first decade* [Researcher]



Fig. 13: *Integration cores of Mosul at 500m radius, the second decade* [Researcher]

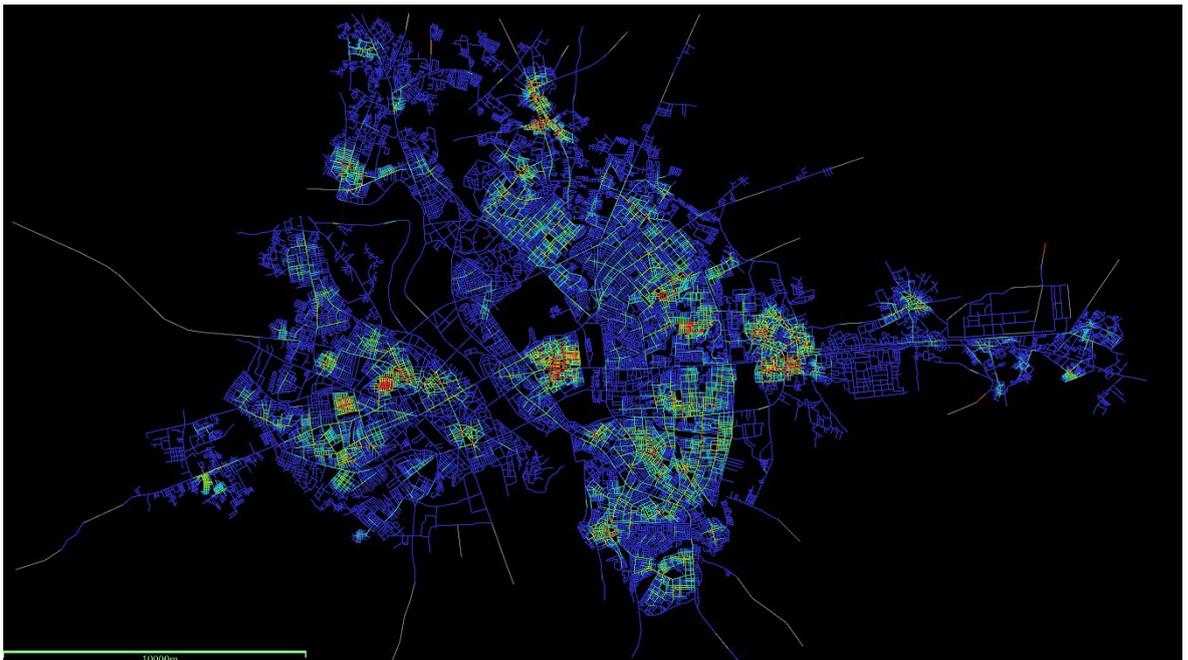


Fig. 14: *Integration cores of Mosul at 500m radius, the third decade* [Researcher]

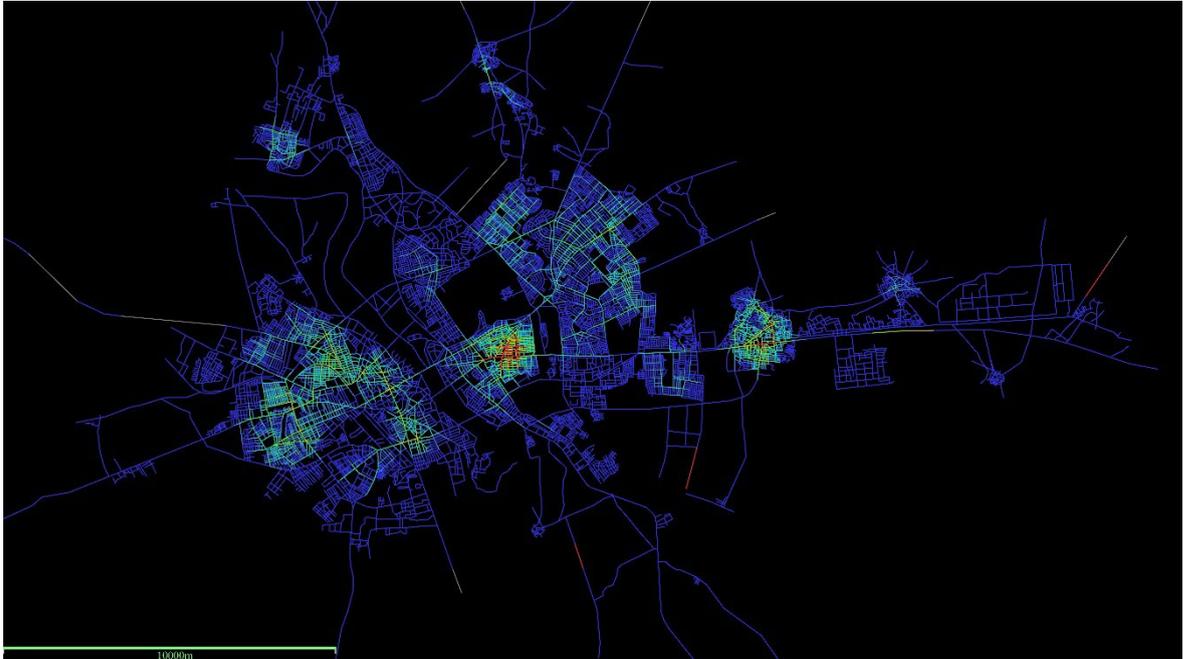


Fig. 15: *Integration cores of Mosul at 1000m radius, the first decade* [Researcher]



Fig. 16: *Integration cores of Mosul at 1000m radius, the second decade* [Researcher]

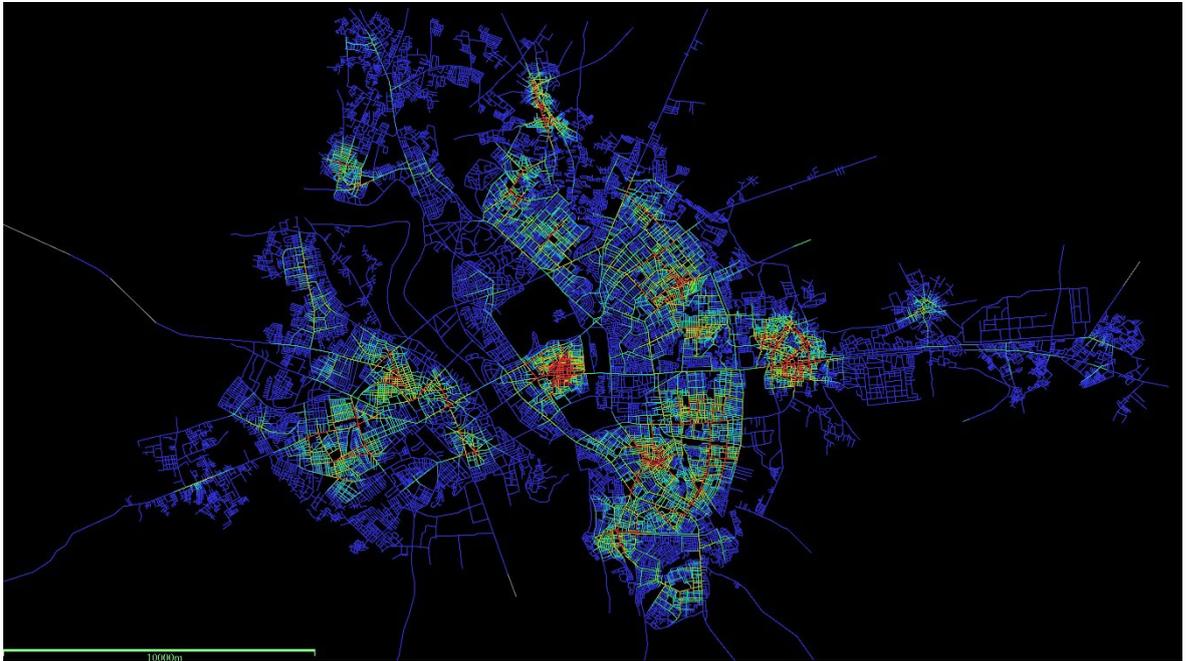


Fig. 17: *Integration cores of Mosul at 1000m radius, the third decade* [Researcher]

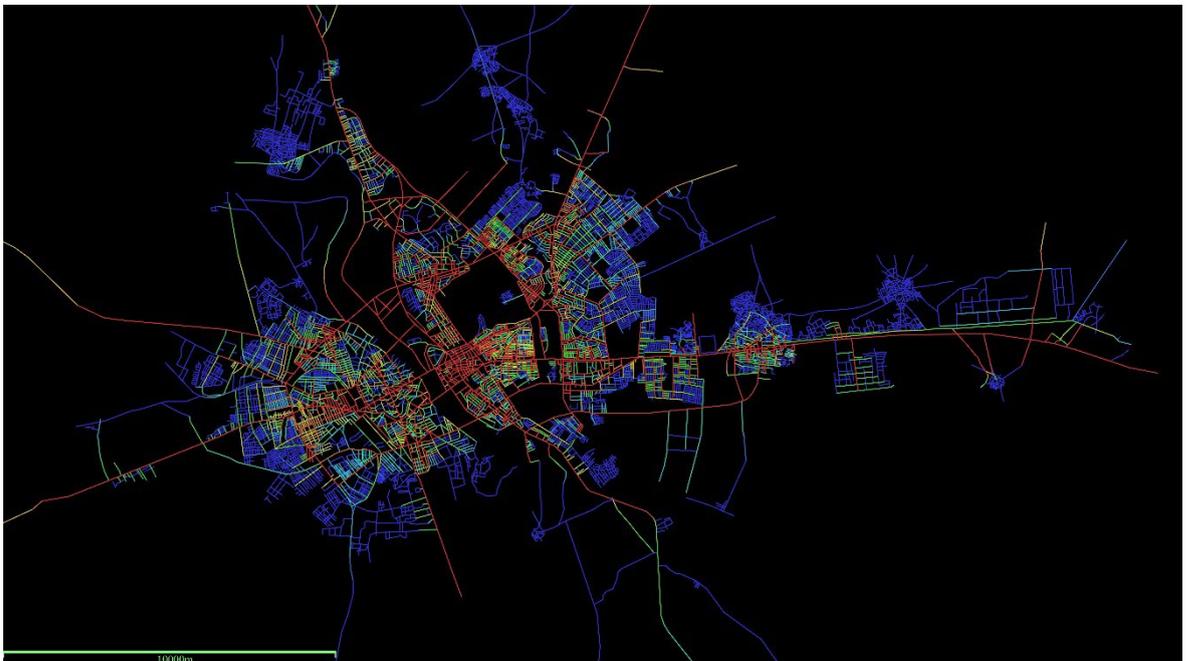


Fig. 18: *Integration cores of Mosul at Nm radius, the first decade* [Researcher]



Fig. 19: *Integration cores of Mosul at Nm radius, the second decade* [Researcher]

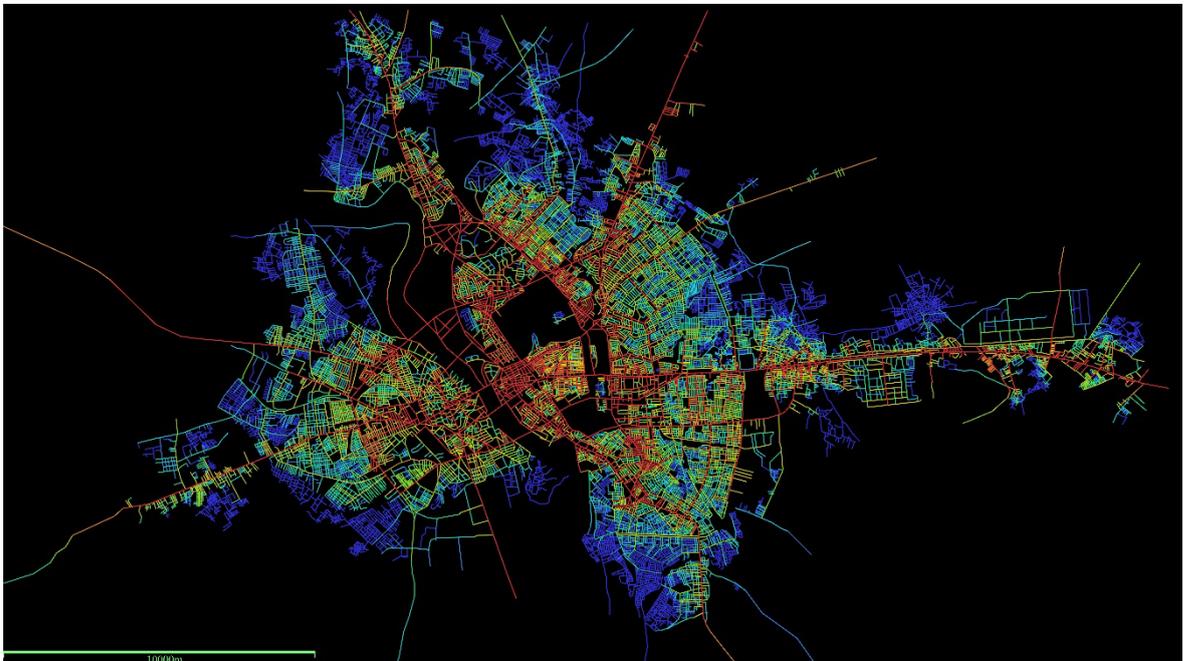


Fig. 20: *Integration cores of Mosul at Nm radius, the third decade* [Researcher]

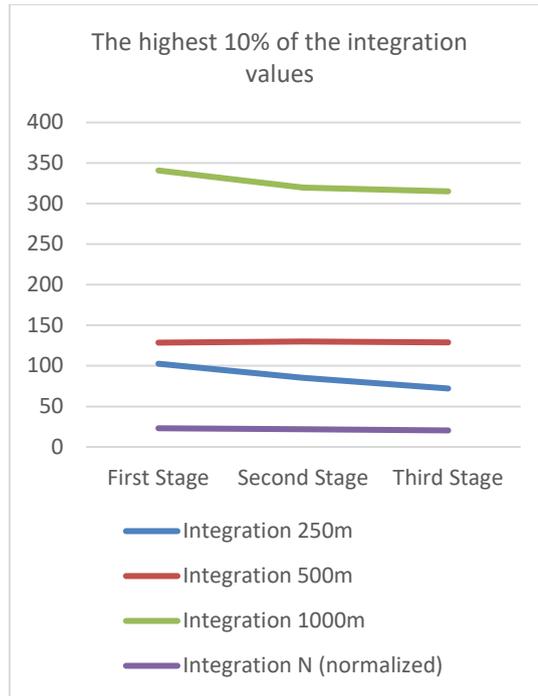


Fig. 21: *The change in the averages of the highest 10% integration values* [Researcher]

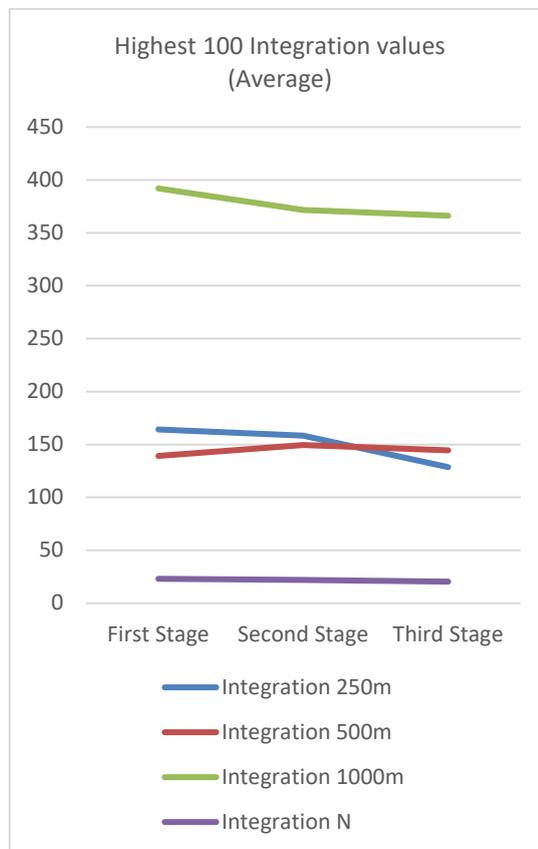


Fig. 22: *The change in the averages of the highest 100 integration values* [Researcher]