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The Building Stock in the City of Dubai: *A Survey Methodology*

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ABSTRACT

In 2003, new building regulations were introduced in the city of Dubai. In 2012, the municipality requested a survey of every building that existed prior to that year. This paper documents the method used for this significant undertaking, not performed by any other large city. The survey was conducted using a combination of Global Positioning System (GPS)-enabled photography and field visits. Multiple images were taken of every street, resembling progressive film imagery, with every building recorded multiple times in the image sequence. The location-tagged images were superimposed on a city map and compared to historical satellite maps of the city from Google Earth history timelines. Whenever the photographic data was not enough to adequately classify a building, field visits were conducted. That was necessary for around 10% of the city structures. The fieldwork was conducted by two teams, each comprising two engineers, and took four weeks to complete. The results showed that, in 2003, there were around 37,000 buildings in the city. Of those, almost 89%, were low-rise (1–2 floors) and largely single-unit residential houses. Nearly all buildings were found to be built after the mid-1980s, and in very good structural condition. The system described in this paper may be applied to any other large-scale city building survey.

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1. INTRODUCTION

The major cities around the Middle East Gulf area share many similarities. They are in a hot arid region, they primarily exist around the water mass of the Gulf itself, they almost exclusively grew into large urban centers within the last 50–70 years, mainly through immigration (Molotch, H., & Ponzini, D. 2019). They also share similar regulations, laws, government systems, and use similar construction materials. All these commonalities led to the cities themselves having broadly similar growth patterns and morphologies (Molotch, H., & Ponzini, D. 2019).

City buildings differ by function, type, architecture, height, finishing, and many other particulars. Conducting a survey to categorize the building stock would, by necessity, have to be based on the purpose of such an effort so that the variables can be determined. A brief background will shed light on the goals of this one.

In 2012, Dubai Municipality contracted Ajman University to survey the building stock in the city of Dubai. The purpose was to document the city as it was before the introduction of the 2003 building rules, which set a maximum range of thermal transfer values for walls and roofs. The survey was designed to catalog the buildings that were built before these rules took effect. The data collection is limited to the factors that might be involved in reducing the city's cooling load.

This work focuses on the methodology that is involved in collecting urban data. The scale and magnitude of the work initially daunted the research teams, but the data collection system proved quite efficient and took significantly less time and effort than had been expected.

The fieldwork for this survey included the creation of a pictorial database of every building in every street at that time, and comparing it to 2004 satellite imagery from the Google Earth history timeline. Accordingly, the results were documented and categorized, building by building.

In 2012, AlNaqbi and others attempted a survey of existing buildings in the UAE. They tried to gather the information from municipality and government agency archives, and were hampered by the limited availability of some records (AlNaqbi, A., AlAwadhi, W., Manneh, A., Kazim, A., & Abu-Hijleh, B. 2012). Their findings reflect those limitations, which are quite divergent from this paper.

Most building surveys have been conducted on less than a city-wide scale. Several have been instigated after earthquakes to assess the damage. In 1994, after the Northridge earthquake in the county of Los Angeles, a survey was performed to determine connection damage and, thus, to evaluate the reliability of conventional connections in steel moment-resisting frames (MRF's). 51 MRF buildings were inspected, and survey forms were completed by 14 independent engineering firms. Many inferences were derived from the data obtained. Of these, a major finding was the lack of correlation between damage and structural characteristics (Youssef, N. F., Bonowitz, D., & Gross, J. L. 1995). More recently, a similar study was conducted following the 2015 Nepal earthquake. This was a reconnaissance conducted in the Kathmandu Valley to highlight the damages resulting from the disaster (Shakya, M., & Kawan, C. K. 2016). Both of these studies were scoped specifically to the structure of a pre-designated number of buildings, rather than a city-scale survey. In both these surveys, the methods were designed for the purpose of the survey. The first was a thorough structural analysis, and the second was a visual evaluation.

A sample of 220 buildings in Reykjavik was surveyed by the Icelandic Building Research Institute to evaluate the overall state of maintenance and performance of existing buildings. Information was acquired from two surveys: one where respondents were owners or tenants of the selected building; the other where a building's condition was evaluated by researchers. The results summarized the conditions that required maintenance and/or renovation (Marteinsson, B., & Jónsson, B. 1999). The methods, again, concerned only certain pre-designated buildings that had already been deemed problematic, and the in-depth approach was only possible due to this factor.

In Poplar Bluff, Missouri, in the years 2012 to 2013, a survey was conducted in response to a new zoning classification. The scope, in terms of building elements and urban planning, was quite broad, including structure, cladding, building use, condition, and parking. It is comprised of a total of 27 commercial blocks containing 68 buildings. The survey found that only 17% of the buildings surveyed were in good condition (L. Foley, T. 2013). While this was a broader survey than those mentioned above, it still assessed only a limited subset of buildings. Its purpose was mainly documentation for planning and city zoning purposes.

Other surveys were even more limited. Marteinsson and Jónsson conducted a small survey in Stockholm on building performance and maintenance (Marteinsson, B., & Jónsson, B. 1999), Chung and Rhee surveyed the buildings on a university campus for opportunities towards energy conservation (Chung, M. H., & Rhee, E. K. 2014), and Dili et al. surveyed occupants of residential buildings in Kerala regarding thermal comfort (Dili, A. S., Naseer, M. A., & Varghese, T. Z. 2010). In neither of these cases was it necessary to construct the type of database required when studying a large amount of data.

A different kind of survey, conducted by Dascalaki et al. in 2011 in Greece examined Hellenic buildings as a case study for potential energy savings from various typologies. Simulation results showed that even the application of basic measures, such as thermally insulating building envelopes, can potentially achieve good energy savings (Dascalaki EG, Droutsa KG, Balaras CA, Kontoyiannidis S. 2011). This study surveyed typologies only; no survey of buildings was involved.

All the surveys above were specific to certain problems, as is this project. In each case, the method was tailored toward the issues in hand. No survey of buildings in an entire city was found. The scale of the work involved is entirely distinctive.

2. THE CITY OF DUBAI

The best-known cities on the Arabian side of the Gulf are Abu Dhabi and Dubai in the UAE, Kuwait City in Kuwait, and Doha in Qatar (Molotch, H., & Ponzini, D. 2019). They all share many urban, regional, and political characteristics. They are relatively new, having risen to prominence within the last 80 years (Molotch, H., & Ponzini, D. 2019). Their populations range from 0.64 million in Doha to 2.889 in Dubai, and 3.13 million in Kuwait City (populationstat. 2020). They They are all coastal, and share a similar hot climate which ranges from the lower teens (Celsius) in winter to the mid-forties in summer (accuweather. 2020).

Dubai itself is a rapidly expanding multicultural city. In the '50s, it was a small fishing and trading center. Houses were built of palm reed. Only a few large buildings existed, constructed from coral stone. With the rise of oil prices and the introduction of cement in the '60s, Dubai's economy expanded into tourism, finance, and business. The city continues to grow rapidly due to flexible immigration policies and a generous wage structure. The large majority of the population are expatriates (Damlūji, S. S. 2006).

The city center was built around the two sides of the Creek, a navigable waterway that connects an interior lagoon with the Gulf. The first multistory buildings, built in the 70's and 80's in the old city, range mainly from 2–10 stories high (Damlūji, S. S. 2006). Many of the newer developments of the 90's and later are modern high rises, reaching as high as the record-breaking Burj Khalifa's 828 m (burjkhalifa. 2019).

Since 1950, Dubai's population grew by a factor of about 100, while its urban built-up area increased around 400 times. Dubai's growth is economically driven, but its urban spatial development has, so far, been design-led (Alawadi, K. 2017). In 1968, the government started implementing the National Housing Scheme. The state's focus on supporting the welfare of the local population by subsidizing plots for its citizens extensively altered Dubai's housing landscape. This policy facilitated suburban growth.

The majority of work written about Dubai in the urban planning literature portrays either the city's history, its rapid development, or its informal urbanism (Alawadi, K. 2017). This study is intended to provide quantitative data about the existing building stock in Dubai and to assist the city's decision-makers.

The climate in the UAE is hot and arid, with cool winter weather, and hot, humid weather in the summer. The temperature in winter is, on average, around 23°C. Therefore, interior thermal comfort in winter is not of as much concern as in summer (Mushtaha, E. & Helmy. O. 2016). Summer, in the UAE, extends from May to October, when temperatures range from 28°C to 36°C, peaking around 48°C in the stifling months of July and August (Böer, B. 1997; climate-data.org. 2019). Buildings use air conditioning all year round (Damlūji, S. S. 2006), which stresses energy consumption.

3. DATA COLLECTION

In young countries like the United Arab Emirates, the last three decades have witnessed a flurry of activity in the building sector. In response, regulators have had to develop rules to organize the expansion including, in 2003 under Decree 66 in Dubai and in 2007 in Abu Dhabi, compulsory regulations for building energy conservation. The increasing costs of energy and the drive to reduce CO_2 emissions led to the further standards and codes, such as Estidama in Abu Dhabi in 2010, and Dubai Green Regulations in 2011 (Awadh, O. 2017; Dubai municipality website, 2020; Dubai Municipality, Green Building Regulations and Specifications, 2019).

To assess the environmental situation of the city as it currently stands, a survey of non-insulated, pre-2003 regulation buildings was necessary, the purpose being to find how many buildings still exist in the city that fall below the thermal properties prescribed by the 2003 regulations, what their impact is, and what might be done to improve them. Specifically, the survey was to reveal the following:

- Which existing buildings were built before the 2003 rules?
- What is the current condition of these buildings?
- Where might thermal refurbishment measures be most effective?
- On which buildings should these measures be applied?
- What would the effect be on the energy consumption of the city?

3.1. BUILDING CLASSIFICATION

Buildings were classified on two lists of criteria. The first list comprised items that might affect cooling and heating. The second concerned elements that might result in legislation to reduce the energy consumption of the city. It was also necessary to keep the number of items within a practically manageable range. Starting from a large pool of possible categories, the number was eventually whittled down to seven that were deemed to be the most relevant. This was done after consultation with the municipality. The final list included building function, age, number of floors, construction and material, window type, roof type and roofing, and wall cladding.

During the pilot survey, these items were reduced to the ones that vary from one building to the other. Windows, for instance, were excluded from the final count because all the windows in Dubai at the time, without fail, were aluminum. Roofs were all concrete except when the construction was steel, which is listed under "Construction Systems and Material". The final property list is in Table 1.

3.2. SURVEY STRATEGY

The first point of contact was Dubai Municipality itself. The records of all buildings were requested from their files. It was found that they are stored on their GIS systems. Alternate strategies were also considered. One was to fill in notes and information on-site for each building. Another was to take photos with GPS tags, and then determine the conditions from the pictures. To decide on which strategy would work best and how it should be conducted, a pilot survey was run first.

3.3. The Pilot Survey

The pilot survey was performed to test the prospective strategies for data collection. Speed, convenience, and accuracy were evaluated.

First strategy: Collecting the data from municipal records. This was the obvious choice. While the data are stored on the municipality's GIS system and are confidential, we were told that we would be allowed access. However, according to our estimates, searching through municipal records online for each building's data to find the specific information we needed would take time, especially for outdated data, which made up the majority of ours and was housed in the form of digitally scanned paper, not database records. In such

1. Building Function	
Four sub-classes:	Residential
	Commercial
	Industrial
	Cultural+: cultural, educational, and public facilities
2. Building Age*	
Considering that the survey was for pre-2003 buildings, that year was taken to be the baseline. Buildings that were finished in that year were classified as new. In the original survey, the sub-categories were defined as listed in the right column. However, they were changed in this paper for the reasons that will be discussed later.	New: 2003 relatively new look, often used cladding. Modern design.
	Declining: design from the late 80s and 90s, reasonably good finishing material. Missing the new look of modern Dubai but not affected too much by aging.
	Old: poor construction. Aging finishing. Simplistic designs. concentrated in the older crowded areas of Deira and Bar Dubai
3. Number of Floors	
These were chosen to loosely match Dubai Municipality categories and terminology.	G+1: ground floor plus one
	G+2 to G+5
	G+6 to G+13
	G+14 floors and higher
4. Construction Systems and Material	
The construction systems most widely used in Dubai were:	CB+CF: Concrete block + concrete frame
	CB+SF: Concrete block + steel frame
	SP+SF: Sandwich panel + steel frame
	Others
5. Cladding	
Cladding was introduced to Dubai in the nineties. It was allocated as a separate category because some of the systems include a layer of thermal insulation. This is especially true of the most widely used system by far, aluminum cladding. The sub-categories are:	No Cladding
	Aluminum
	Marble, granite, stone (mrbl, grnt, stn)
	Other cladding; glass mostly but also ceramic, wood, bricks, unidentified synthetic material, etc. plus a few materials that were rarely used and not worth a separate category.

Table 1 Building properties that were surveyed.

* Due to new data sources becoming available at the time of writing this paper, the methodology and dating were updated accordingly from the original survey.

cases, the data would have to be manually extracted. It would also limit the sharing of the workload since the municipality could not afford us multiple terminals. Nor would we be allowed to work on holidays or after hours. Assuming that each building would require five minutes of searching, the work would take 388 working days.

Second strategy: collecting data directly on location. This system was the first one tested. After working on one street for about 45 minutes, it became clear that taking notes on-site was time-consuming, challenging, and impracticable. The wind played around with the maps and papers, walking the whole length of the street while taking notes was slow, and the weather was unpredictable and sometimes interfered with the work, especially the hot sunshine. Furthermore, the information taken manually could not be checked later for errors, nor could missing information be filled in without revisiting the site.

Third strategy: GPS-tagged photos. The third method, taking pictures with GPS tags, was more challenging technically, but proved more efficient and much faster. Information and accuracy could be checked and rechecked, and the images remain as a database for future use. However, it was also clear that images might, in certain conditions, not reveal all the information necessary.

The final survey data was collected from street photos and augmented by site visits where and when required. The latter was the case in the industrial areas, for instance, where some of the information could not be determined from the photos alone. The structures were sometimes not initially clear, with many comprising a combination of concrete blocks and insulated corrugated panels in a variety of combinations. Furthermore, while some were enclosed air-conditioned buildings, many were merely non-air-conditioned storage sheds or covered, non-air-conditioned workshops. The difference between the two was often not obvious from the photos. For these areas, site visits were undertaken on foot, and every building was visited. In many cases, the team had to venture inside to complete the information. It was fortunate that the survey teams were almost always granted access. In only one case was access only partially approved: a perfume factory where the interior temperature was a sensitive issue. Nevertheless, enough of it was seen to complete the information.

It was noted during the site visits to the industrial area that sandwich panels were not insulated, nor was there any other thermal treatment to save on air conditioning; most structures were open covered spaces with no thermal control. Insulation was present only to reduce insolation. Figures 1–4 show samples of conditioned and non-air-conditioned spaces in that district.

3.4. THE FIELD WORK

The data were collected by two teams, each involving two engineers. One engineer was the driver while the other took the photos and directed the driver along the pre-designated route. Photographs were taken using two mobile phones with high-quality cameras, GPS tagging, and Internet data connectivity to augment the GPS accuracy. A3 sized Dubai 2004 maps and a GPS navigator were included in each team's field kit.

The city map was divided into blocks to make it easy for the teams to classify the collected information and distribute the workload, as shown in the "master map" (Figure 5). Each team was assigned geographically adjacent blocks. The blocks were outlined according to the built-up specifications of each segment. The large blocks were then divided into smaller sub-blocks which could be surveyed in one or two outings. For example, block 2A comprised sub-blocks 2A-1, 2A-2, 2A-3, etc.

The first step before each outing was to study each block on the map to develop an efficient route. A starting point and a route were selected. Outings took as long as 10 hours, depending on traffic and the location

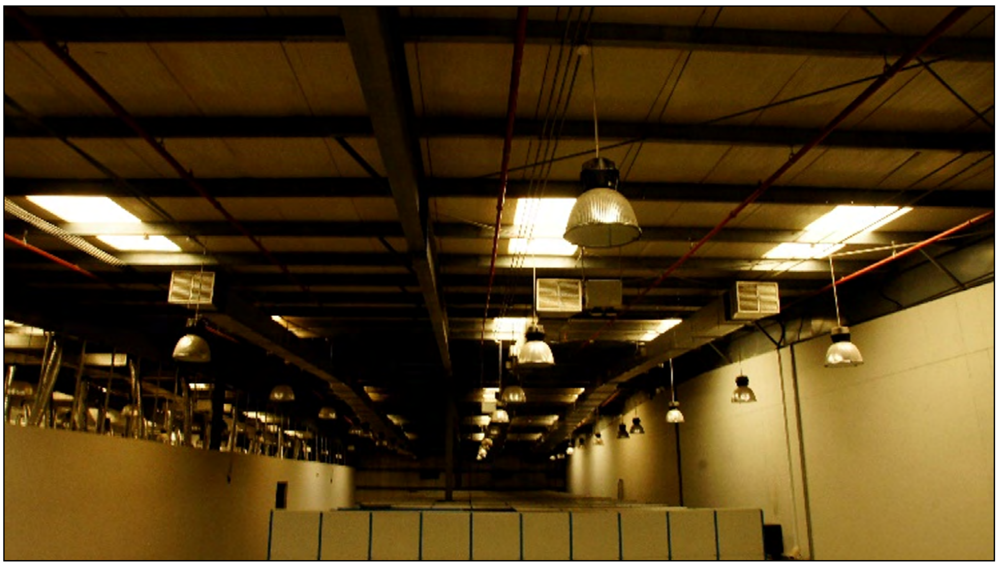


Figure 1 Air-conditioned interior in the industrial area (by author).

Figure 2 Non-air-conditioned space (by author).

Figure 3 A street in the industrial area in the Al Quz district (photo taken by author).

Figure 4 Mixed conditioned space. The offices at the bottom of the picture are cooled; the remainder of the interior is not (by author).

of the block. For instance, ten days were needed to cover the highly-density area from the Creek to Barsha, represented by blocks 2A, 3A, 2B, and 3B, by one team. The less-dense, more homogenous, modern parts of the city were much easier and faster to survey. The entire field survey took three weeks.

The cameras were hand held inside the car, and manually aimed to take images of both sides of the street. Figure 6 shows a sequence of images of one side of one road in the Bar Dubai district. Each building appears multiple times in each series of shots.

After collecting and downloading all the photos, they were imported into photo organizing software called JetPhoto Studio. This software is used to locate the images on a map by their embedded GPS tags. Figure 7 shows how each photo is represented by a red marker on the map. This system allowed the team to peruse each street, frame-by-frame, on a computer screen, similar to

Figure 5 Dubai city as it was in 2003, divided into blocks for surveying (Base map courtesy of Google Earth).

Figure 6 Sample sequence shots on one side of one street. The colors are off due to the front glass tint in the car.

Figure 7 Photo location markers on the map.

watching a slow-motion video. JetPhoto Studio indicated the location of each image as it was displayed, greatly speeding the process.

Each team then went through the images they had taken, one by one, as if journeying again through the city, and recorded the required information directly to an Excel spreadsheet.

It should be noted that the system used to determine building age in this paper is more accurate and not the same as written in the original survey. For that one, building age was estimated from the construction details of the period. At the time, Google Earth's "Historical Imagery" for Dubai ended with 2004 and thus was not relevant. However, that presently extends back to 1984. Consequently, the maps, dates, and data for this paper were modified and updated using this new information supplied by Google Earth maps.

3.5. DATA ORGANIZATION AND VERIFICATION

After all the information was collected, a Microsoft Excel template was designed to standardize the sector summaries. Each sector's summary data was input by the same team that surveyed it. A summary was then produced for each sector. Each summary sheet showed the location of the survey site, a sector map indicating the prevailing function, the building classifications, the statistics within the sector, and representative pictures of the location. Part of the Deira sector can be seen in Figure 8.

A final, city-wide master sheet was produced from the sector summaries. Figure 8 shows a screenshot of a small part of the final table.

An element of human error appeared during verification. The total number of buildings in the city did not always tally between the categories, viz. 37,246, 37,174, 37,270 and, 37,270. Nevertheless, the greatest discrepancy between a count and the mean (37,240) was negligible at 0.0161%.

It may look like the total number of buildings using cladding is higher than all the figures listed above, at 38,059. The reason is that some buildings used more than one type of cladding, and were thus (correctly) entered more than once in the table. This count thus indicates incidences of cladding, not of buildings.

4. SURVEY OUTCOMES

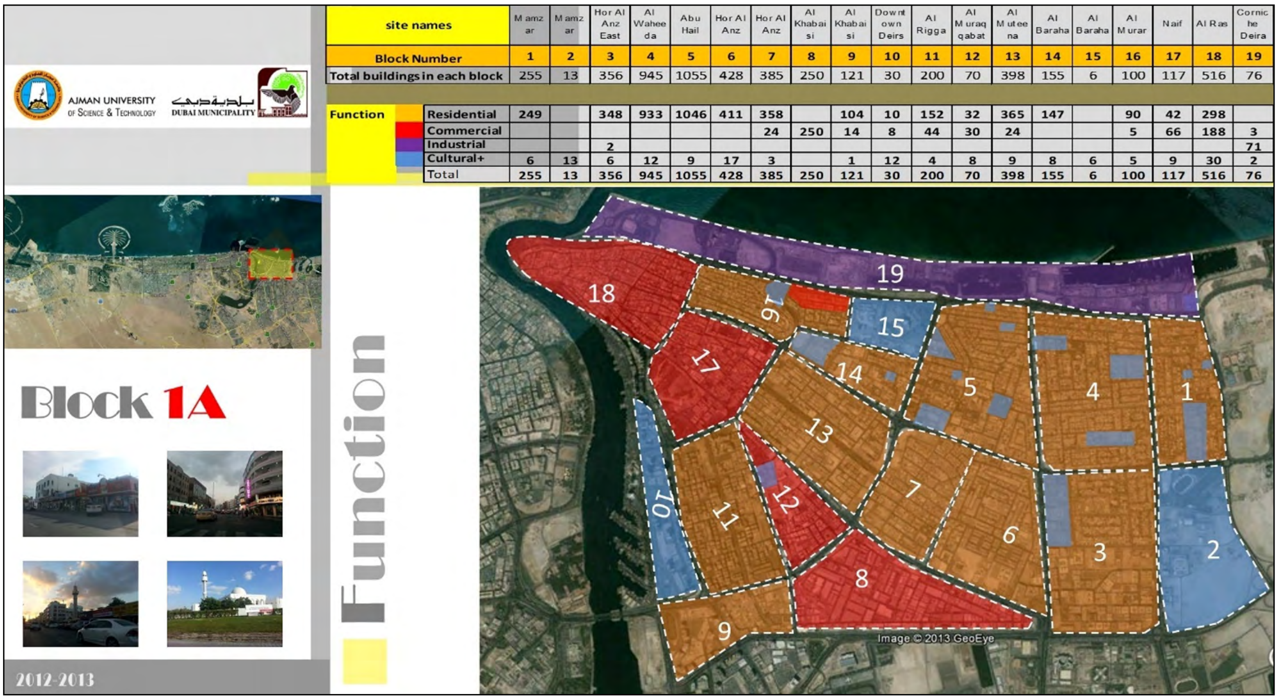
After the data was entered into the spreadsheet, a sector-by-sector verification was undertaken. At this point, a difference of opinion arose regarding whether buildings still under construction in 2003 should be included or not. The decision was that, since the building permits were issued well before the 2003 regulations update, they would not be built according to the new standards and, therefore, should be included.

4.1. BUILDINGS BY FUNCTION

The survey data showed that, while present cities might contain large centers of business, industry, and commerce, the urban expanse was still, by and large, a refuge for people to live and congregate in. Most of the built-up area in the city, by far, consisted of residential buildings, making up 77% of the total. Industry was a distant second. The statistics and distribution of these functions are shown in Figure 9.

The map reveals that the commercial and cultural+ buildings were mostly concentrated in or near the old city center around the two sides of the Creek, in the zones designated 1A, 2A, and 1B. The industrial areas are on the extreme edges of the city and at the ports. A more homogenous distribution can be seen in the new parts of the city to the south-east and south-west, whereas the old parts are mixed, with multiple functions within each city block. This difference reflects the land use designations issued by the city planners for the new parts, whereas the older parts were less controlled. The farther from the old city center the sector is, the clearer and more specific the land-use becomes.

Most of the buildings were of easily recognizable functionally, especially the industrial, cultural, and strictly commercial buildings. However, the functions of some of the multistory buildings were less clear. The municipality restricts land use and building permits for residential or business designations, which eased the burden of recognition on the survey teams. However, it also allows for exceptions, so a margin for error must be allowed. Furthermore, a building might correctly be designated residential but have a commercial ground



site names		Mamzar	Mamzar	Hor Al Anz East	Al Waheeda	Abu Hail	Hor Al Anz	Hor Al Anz	Al Khabaisi	Al Khabaisi	Downtown Deirs	Al Rigga	Al Muraqqabat	Al Muteena	Al Baraha	Al Baraha	Al Murar	Naif	Al Ras	Corniche Deira
Block Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Total buildings in each block		255	13	356	945	1055	428	385	250	121	30	200	70	398	155	6	100	117	516	76
Function	Residential	249		348	933	1046	411	358		104	10	152	32	365	147		90	42	298	
	Commercial							24	250	14	8	44	30	24			5	66	188	3
	Industrial			2																71
	Cultural+	6	13	6	12	9	17	3		1	12	4	8	9	8	6	5	9	30	2
	Total	255	13	356	945	1055	428	385	250	121	30	200	70	398	155	6	100	117	516	76

Figure 8 A sample table of the data sheet for part of the Diera sector numbered as Block A1 by the survey team. Its location can be referenced from the master map in Figure 5.

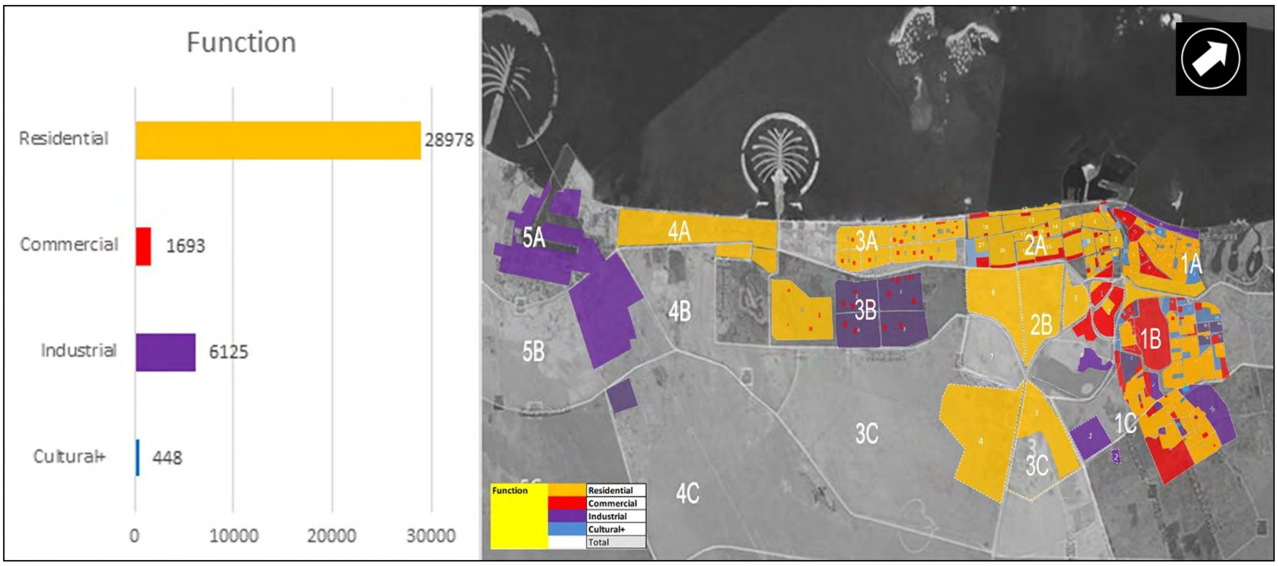


Figure 9 Number of buildings according to their function and location in the city (Base map courtesy of Google Earth).

floor with shops facing the street. The classification of buildings by function hence hides the full extent of commercial activity, which is actually larger than recorded in this survey.

4.2. BUILDINGS BY AGE

Unlike the other building descriptors, the building's age was not recorded through the survey but instead using the timeline indicator from Google maps.

The original purpose of classifying buildings by age was to determine how many were old enough, and in such a bad state, that they would not be worth retrofitting thermally. However, the survey revealed that even the oldest buildings were in good shape.

Interestingly, Dubai before 1986 was quite small, low-density, and concentrated primarily around the entrance of the Creek. Neighboring Sharjah was the bigger city. Nevertheless, by 2003, Dubai had expanded into a large urban sprawl of tens of thousands of buildings.

The maps in Figures 10, 11, and 18 show that the city expanded mostly along the waterfront through to the nineties, then reached inland. It should be noted that

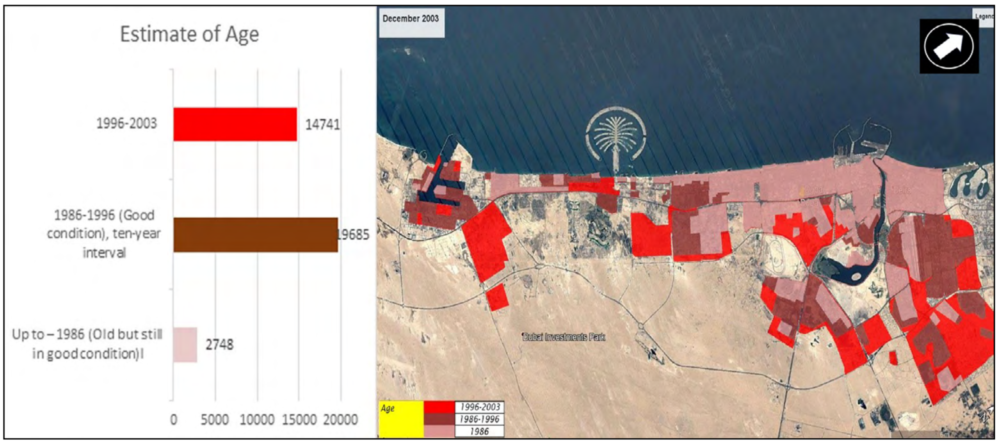


Figure 10 Number of buildings according to their age and location in the city (Base map courtesy of Google Earth).

Figure 11 Dubai city historic progression from 1986 to 2003. (Baseline 2003 map image courtesy of Google Earth).

Sharjah lies to the north-east of Dubai, curtailing Dubai's growth in that direction.

The recency of Dubai's rapid growth is illustrated by 34,426 buildings having been erected between 1986 and 2003, in contrast to only 2,748 before that.

4.3. BUILDINGS BY HEIGHT

While modern Dubai is imagined as a city dominated by skyscrapers, the data in Figure 12 for 2003 describes a different scene. Most buildings were actually low-rise, only one or two stories high. Looking back at the function distribution numbers in Figure 9, this should come as no surprise. Most of the 28,978 residential buildings are single-unit houses. Add to that all the 6,125 industrial buildings and most of the 448 cultural+ buildings, and the picture becomes clearer. The size and visual prominence of the skyscrapers create an impression of height that does not match reality.

The accompanying map in Figure 12 shows the height distribution of buildings in 2003. In Dubai municipality, the code 'G+1' means a two-story building, i.e. ground plus first floor. Thus G+2 is the ground floor plus two more floors, and so on.

The red high-rise area in the south-east, designated 4A, was, in 2003, a new high-rise suburb called "The Marina". It is presently a dense modern neighborhood that has become a magnet for more high-rise developments, as can be seen in Figure 13. However, in 2003, it was a new neighborhood with only a few buildings approaching their final construction stages, hence the low building count despite the large area covered.

4.3. 1. Estimated area of each building type

It is possible to extrapolate an approximate built-up floor area for each category by multiplying the average of each unit in that category by the number of units. The

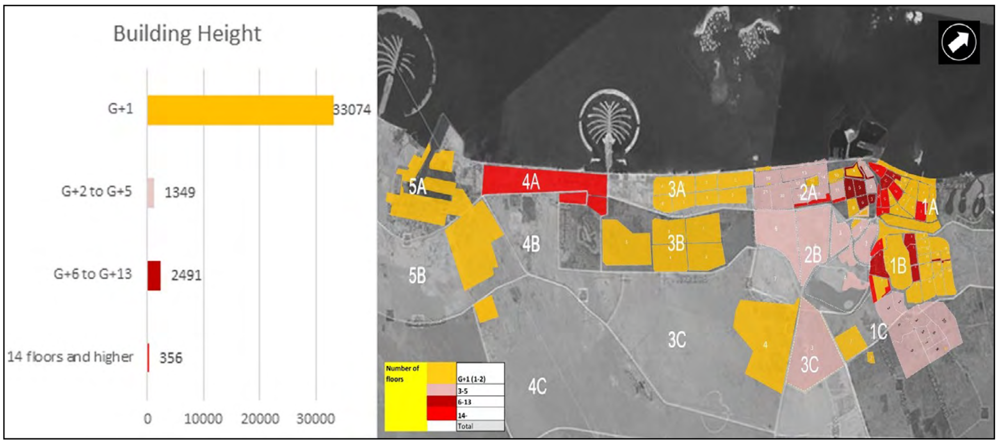


Figure 12 Number of buildings according to height and location in the city as of 2003 (Base map courtesy of Google Earth).

Figure 13 The Dubai Marina. This photo was taken in 2009, however, in 2003 these buildings had just been finished and were still in the process of being occupied (photo by author).

purpose is to roughly estimate how much area requires cooling.

The average area per unit were calculated from a popular online real estate website (Dubai.Dubizzle, 2019), sampling 40–60 units of each category in each data set. The number of units was increased until the 95% confidence interval for the mean was surpassed, indicating that it was significantly reliable. 20% was added to the area of multistory buildings to account for circulation and service space. The results are shown in Table 2.

By multiplying these areas by the number of buildings in each category, the total built-up floor area figure was estimated for each building type. The graph in Figure 14 shows how the areas are distributed accordingly.

While the graph in 12 shows that single and two-story buildings were the most numerous by far, Figure 14 shows that, in terms of functional built-up area, multistory buildings 6–13 stories high, both residential and commercial, contain far more internal space, and account for around 53% of all interior spaces in existing buildings. Villas[1] came a distant second at 16.4%.

4.4. BUILDINGS ACCORDING TO CONSTRUCTION

By far, the most popular construction system in the whole of the MENA region is concrete blocks on a reinforced concrete frame, as shown in the statistics and on the map in Figure 15, and illustrated by the Marina neighborhood photograph in Figure 13. The new industrial areas to the south-east are primarily built using insulated steel sandwich panels on a steel frame, as depicted in Figures 1–4. The older ones in the southwest are similar, but mostly use concrete block walls to support the steel frame top.

4.5. BUILDINGS BY CLADDING

Many of the modern buildings in Dubai use aluminum cladding. As such, it was expected that quite a few aluminum-clad buildings would be found in those that were built before 2003. However, according to the survey stats shown in Figure 16, that was not the case. The

CATEGORY	AVERAGE AREA M²	STANDARD DEVIATION	95% CONFIDENCE INTERVAL	ESTIMATE SERVICE AND CIRCULATION AREA M²	TOTAL AVERAGE AREA M²
Villa (house)	357	151.667	1.54	0	357
Residential flat	172	144.34	1.47	34.4	206.4
Office	155	149.73	1.52	31	186
Industrial	3667	4579.8	46.58	0	3667

Table 2 Average unit area for each category.

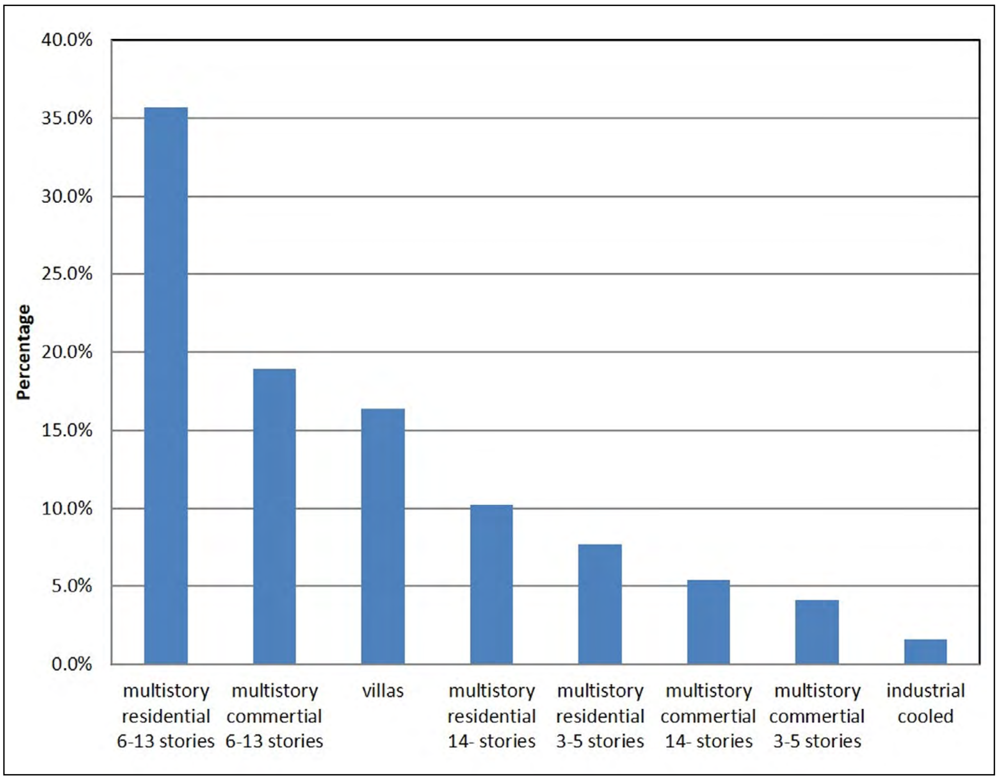


Figure 14 Approximate percentage of built-up internal areas in Dubai by categor.

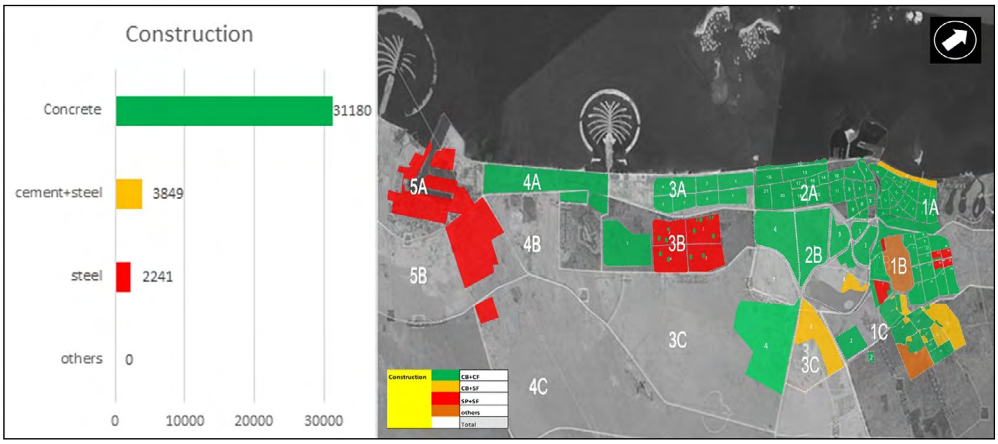


Figure 15 Number of buildings according to their construction and location in the city in 2003 (Base map courtesy of Google Earth).

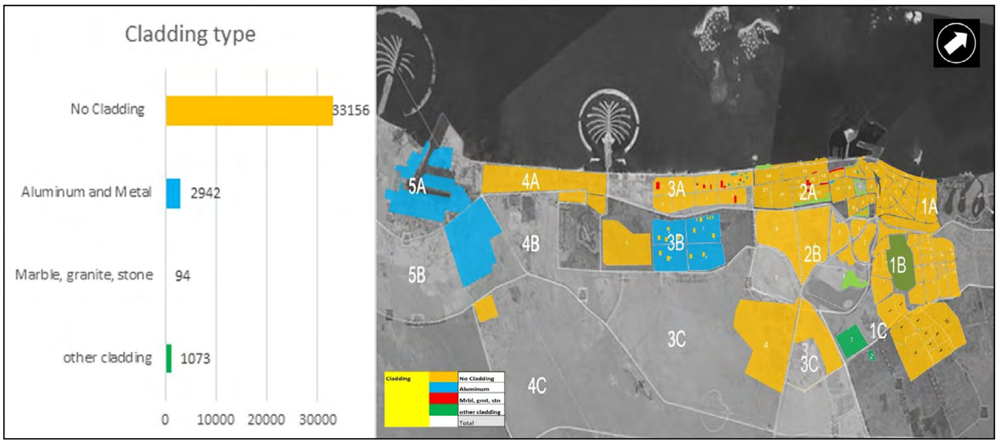


Figure 16 Number of buildings according to cladding by location in the city in 2003 (Base map courtesy of Google Earth).

modern, decorative, long-lasting, dust-resistant, but inflammable aluminum cladding had only just started to appear in that period. Most of the pre-2003 cladding was in the industrial areas and was non-decorative corrugated metal. Consequently, metal and aluminum were consigned to one category. The "other cladding" category was found to be mostly glass.

5. DISCUSSION

Several noteworthy findings have been mentioned in their respective sections separately. Especially notable among those is the predominance of residential buildings, followed by industrial ones. The industrial buildings, generally, were significantly larger than buildings of other types: each single-story warehouse could contain several small individual housing plots, for example. Hence, comparing the number of residential buildings to the industrial does not communicate their contributions to the built-up area.

The other notable finding is how few of the buildings in 2003 were over 14 stories high—only 356, which is merely 1% of the total. A new observer's usual impression is that the city is dominated by skyscrapers.

The fact that most buildings are residential, single-unit houses has significant implications for energy consumption. These structures contain more exterior walls, windows, doors, and openings that are exposed to the ambient outside heat. This allows more of it to penetrate into the interior. On the other hand, because these are low-lying structures, it is easier to insulate the walls using exterior insulation systems (EIS). These have proven very effective (Simona PL, Spiru P, Ion IV, 2017) as well as being easy to install on existing buildings.

Another important result of the survey is to reveal how much each major urban functional sector occupies of the city's built-up area, residential being by far the most prevalent.

5.1. AREA ALLOCATION ACCORDING TO ACTIVITY SECTOR

Dubai is not an industrial city by any means. Before 2003, its economy relied mostly on finance and tourism. Much of the industrial area was dedicated to servicing cars and the building industry. Since the survey data shows how much of the city's built-up area was occupied by each function, the question arises as to whether it can be used as an indicator to profile the economic activity within the city. Figure 17 shows the distribution data of the relevant interior space.

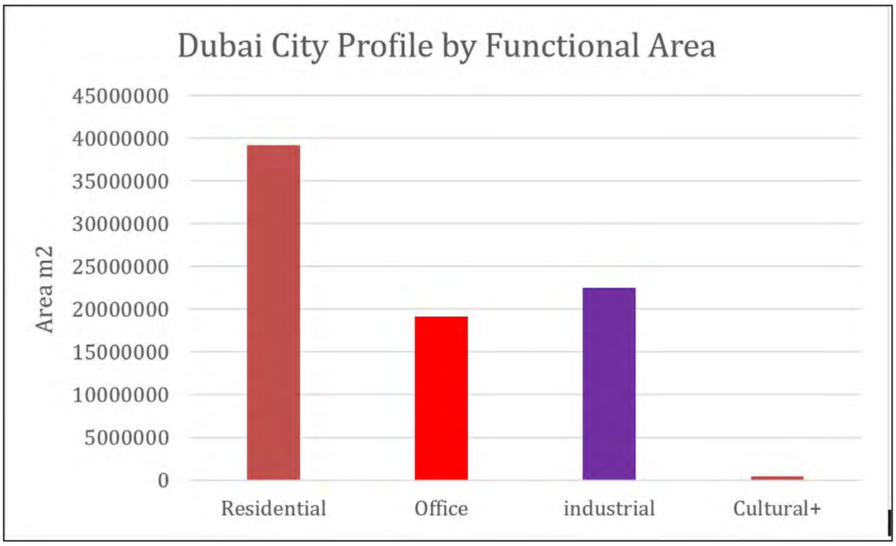


Figure 17 The total built-up area of each building according to activity.

The graph, while interesting, is only a summary indicator of the city's activity, and an incomplete one at that. The commercial area for trade, whether retail or wholesale, is entirely missing. Most retail spaces are on the floor ground of buildings that are categorized as residential, in addition to some multistory commercial buildings. Nevertheless, it still provides a meaningful snapshot of the city at a certain period and an area for further research. It would be much more useful should data from other cities become available for comparison.

5.2. THE CITY'S GROWTH PATTERN

One of the most interesting parts of the survey for city planners and urban designers is how the city grew over the last thirty years. Large cities usually grow over hundreds of years, and much of that history is lost to us. However, Dubai only rose from the desert in the last 80 years, and is well documented (Damlūji, S. S. 2006; Lis S. 2010). Analyzing the survey data along with historical maps and documents, a picture of the city's growth can be discerned that is worthy of further study.

In the early 50's, Dubai was only a small trading hub on the Gulf. Most of the housing was built from reed and palm fronds (Lis S. 2010). Only a few permanent houses existed, built from coral stone. Later in the decade and into the early sixties, with the advent of oil money, the Creek, which connected the city to the Gulf, was dredged, opening the city to shipping trade. A few concrete warehouses and buildings started to appear along its sides. There were few roads, but a new airport was opened in 1959. In the seventies, the city center started to appear around the Creek. It contained modern concrete multistory buildings and a few roads (Damlūji, S. S. 2006; Lis S. 2010, Elsheshtawy; Y. 2009).

During the eighties, which is included in this survey, the city started expanding in earnest. The map in Figure 19 illustrates this expansion. Diera, the part adjacent to Sharjah city in the northeast, was the first to show significant growth (Damlūji, S. S. 2006), but that soon stopped as it hit the borders with its neighboring emirate. Industry started to appear, mostly in the form of car repair workshops. In Bar Dubai to the southwest, development continued. At the extreme southwest, a large modern shipping port, Jabal Ali, was being built. The city started extending along the coast in that direction, beginning with large, opulent villas along the beach. Roads followed, and then further construction along the best-valued real estate property. To this day, most of Dubai is largely a 50 km stretch that parallels the coast. Three modern, 12-lane, parallel highways running in the same direction were built with complicated intersections, and are clearly visible in Figure 18. When the two inland highways were built, they ran through desert; these areas are now quickly being populated. It is notable that, every time a road, shipping port, or airport was built, construction and development followed.

5.3. ENERGY

The survey results in section 4.3.1 show that single and two-story buildings were the most numerous in Dubai in terms of number. However, the type with the most cooled area spaces were multistory buildings of 6–13 floors. The cooling load does not rely on the number of buildings as much as it does on the total area and the specifications of the spaces being cooled. The temptation is to use the area occupied by each type of building as a reference for how much cooling they require. The graph in Figure 17 shows such a distribution. It would seem logical to conclude, from that graph, that the mid-rise 6–13 category is responsible for most of the old buildings air conditioning. However, most spaces in high-rise structures require less cooling due to the fact that they have less exterior surface, being sandwiched between cooled floors above and below, as well as adjacent. Independent houses, on the other hand, are significantly more exposed to exterior heat.

To conclude how the older buildings affect Dubai's energy consumption, a thermal examination of each

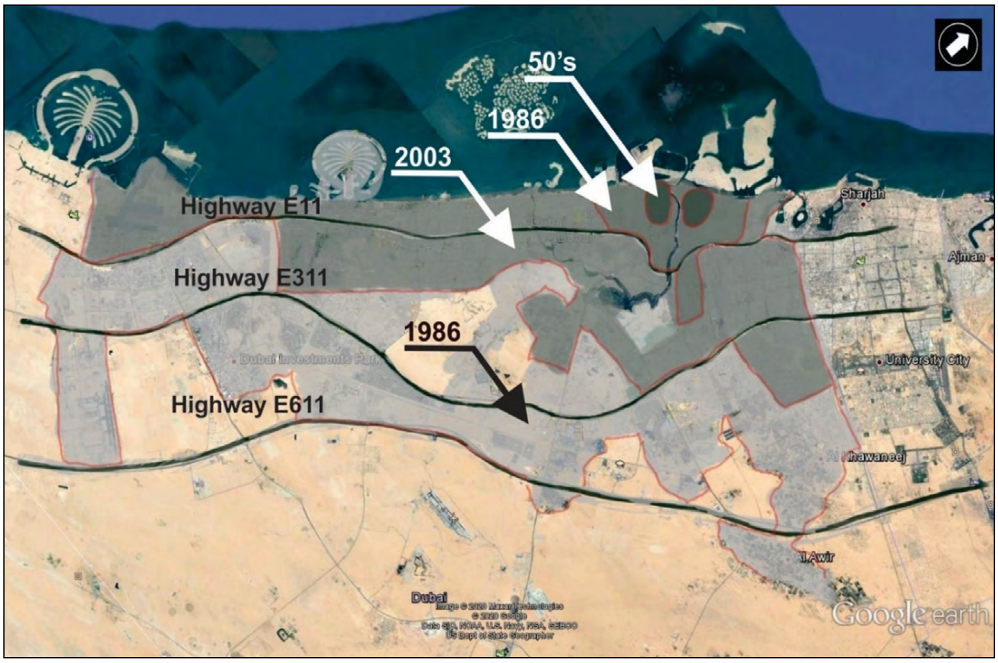


Figure 18 Colored map showing Dubai expansion in the last eighty years from a small village to a modern city in 2020. The first stage is indicated by the two dark ellipses marked by the arrow title "50's". The rest show 1986, 2003, and 2020 stages in succession. (base map courtesy of Google Earth).

type of building must be conducted. The results can then be superimposed on the city through the results of this survey to reveal how much each building type is contributing to the city's energy consumption. Further analysis could also show how much those figures could be improved if those old buildings were thermally treated. While there would undoubtedly be benefits, the numerical analysis could show whether such measures would be financially and politically, feasible.

5.4. MAIN SURVEY QUESTIONS

The main questions that the survey was intended to reveal as listed in section 3 may be summarized as follows:

- Which existing buildings were built before the 2003 rules?
  All the buildings in the survey were built before 2003.
- What is the current condition of these buildings?
  Almost all the buildings were relatively new, and their condition was very good to excellent.
- Where might thermal refurbishment measures be most effective?
  Single and 2–3 floor Villas.
- On which buildings should these measures be applied?
  All the buildings should be insulated but in order of effect, then villas mainly, followed by multistorey 6–13 floor buildings.
- What would the effect be on the energy consumption of the city?
  The data from this survey can be used as a basis to calculate the overall effect, as explained in 5.3 above.

5.5. SUMMARY OF MAIN FINDINGS

The survey of Dubai building stock before the 2003 regulations provided some useful pointers for planners and designers.

- During the 1950s the large majority of local Emiratis lived in huts made of palm reed houses called Barasti (Damlūji, S. S. 2006). By the 1980s, the Barasti had completely disappeared. Regrettably, it is difficult to find even a good pictorial record of these structures.
- Should other cities have a morphology similar to Dubai, especially those in the other Gulf states, then, despite the increasing encroachment of industry, business, and entertainment, they are still largely residential, where the populace finds refuge and work.
- Despite a rapid increase in population and area, Dubai appears to be well planned with a clear assignment of land use, especially in the new areas. This was aided by the fact that most of the city is recently built under the direction of Dubai Municipality planning guidelines. The old city around the Creek is more fragmented.
- City expansion followed real estate and commercial value along the waterfront at first, then shifted towards the interior when the borders of neighboring emirates were reached and travel distances became problematic. The city is still primarily linear and parallel to the coastline.
- Being so new, the city has almost no buildings that may be classified as dilapidated or needing demolition. Present demolitions are usually

motivated by improving commercial real estate and development value.

- Buildings designed before 2003 did not use the modern aluminum cladding that is so widespread in modern high rises. This is important, due to the fire hazard that they have been shown to represent.
- It is disappointing that similar surveys of other cities could not be found for comparison, especially for older cities.

NOTE

[1] An individual house is called a "villa" in the UAE.

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The authors have no competing interests to declare.

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