

TRIALOG 114

A Journal for Planning
and Building in the
Global Context
(Vol. 3/2013 - May 2015)

Oman –
Rapid Urbanisation



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Volume Editors: XXX

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Evaluating the Urban Development and Determining the “Peak Space” of the Muscat Capital Area

Aurel von Richthofen, Sebastian Langer

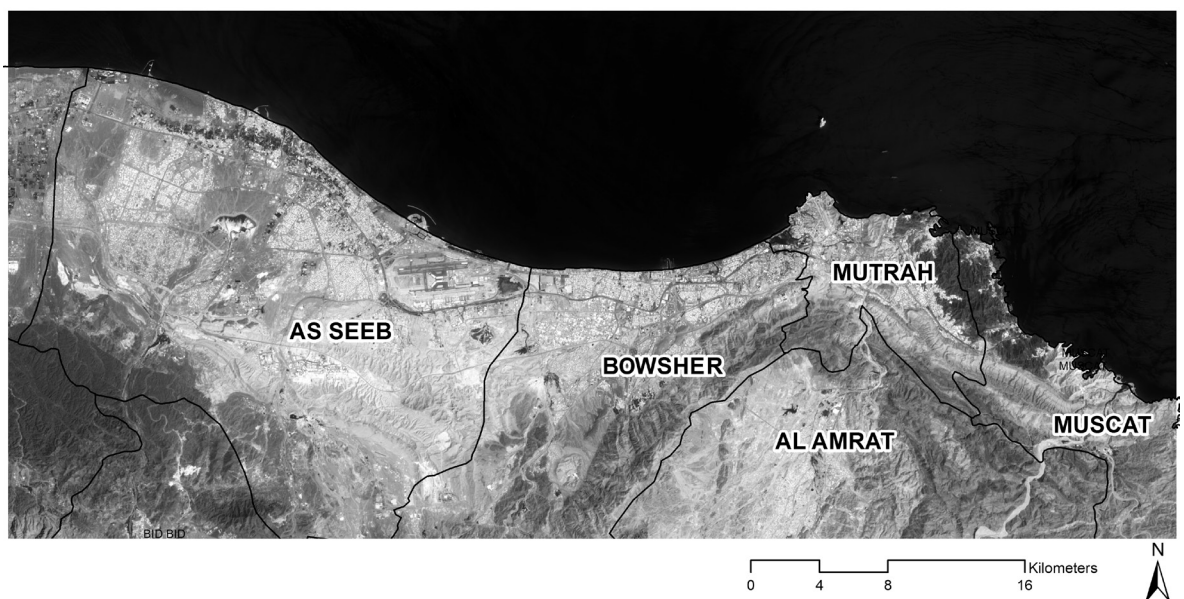
Muscat Capital Area (MCA) hat sich seit der s.g. omanischen Renaissance 1970 rasant entwickelt. Die städtebauliche Ausdehnung kann durch die Auswertung von Satellitenbildern mittels eines eigens entwickelten Verfahrens ab 1984 nachvollzogen werden. Dadurch wird sowohl die zeitliche als auch die räumliche Entwicklung des Stadtraumes nachgezeichnet. Durch die Anwendung zweier Betrachtungsmaßstäbe lassen sich auch Dichteentwicklungen beschreiben. Sowohl in der Auflösung als auch in der Ausdehnung liefert dieses neue, rechnergestützte Verfahren umfangreiche Karten. Die quantitative Auswertung dieser Karten unterstützt die Interpretation der Stadtgenese und erlaubt Ausblicke in die Zukunft. Nach einer Phase der Expansion von ca. 1980 bis 2010, werden Anzeichen einer räumlichen Sättigung wahrnehmbar. Die Grenzen des Wachstums werden mit dem neu eingeführten Konzept des „peak-space“ für MCA interpretiert. Dieser Zeitpunkt ist bereits 2012 überschritten worden. Schließlich wird ein Vorschlag für die Verdichtung des Stadtraumes durch die staatliche Vergabe von Raum statt von Land abgegeben

Introduction

This paper presents a new method derived from Object-Based Image Analysis (OBIA) to generate spatio-temporal and density maps of urbanised areas in arid climates. The case study of the Muscat Capital Area (MCA) is particular interesting since the young development of the city coincides with the availability of LANDSAT satellite data, which dates back as far as 1984 for the area. Moreover, Oman offers a varied urban morphology that can be explained both geographically and historically (Al-Awadhi 2007), yet, in regard to the greater region of the MCA, it has never been examined. OBIA-derived maps allow, for the first time, qualified statements about the spatial development of the city. Analysing the regional urbanisation area, the concept of peak space is established as an indicator for exhaustive resource of land use and limit of urbanisation.

Monitoring urban development in the MCA

Urbanisation in Oman started in 1970 with the so-called Omani Renaissance, a process of economic development and demographic growth focussed in the capital city of Muscat. Within four decades, the MCA developed from small port towns and agricultural villages into an urban expanse housing more than one million people (Scholz 1978). While urbanisation processes were structured by various planning efforts (5-year development plans from 1975 onwards, structure plans from 1989-91, 2020 vision, etc.) and administrated by various governmental entities gradually established since the 1980s (The Supreme Council of Planning, Ministry of Housing, Muscat Municipality, etc.), the actual development of urbanisation has not been monitored systematically. Historians and urban geographers have, however, covered particular aspects



► **Figure 1:** Image of the study area in 2014 with administrative boundaries (wilayah), (LANDSAT archive)

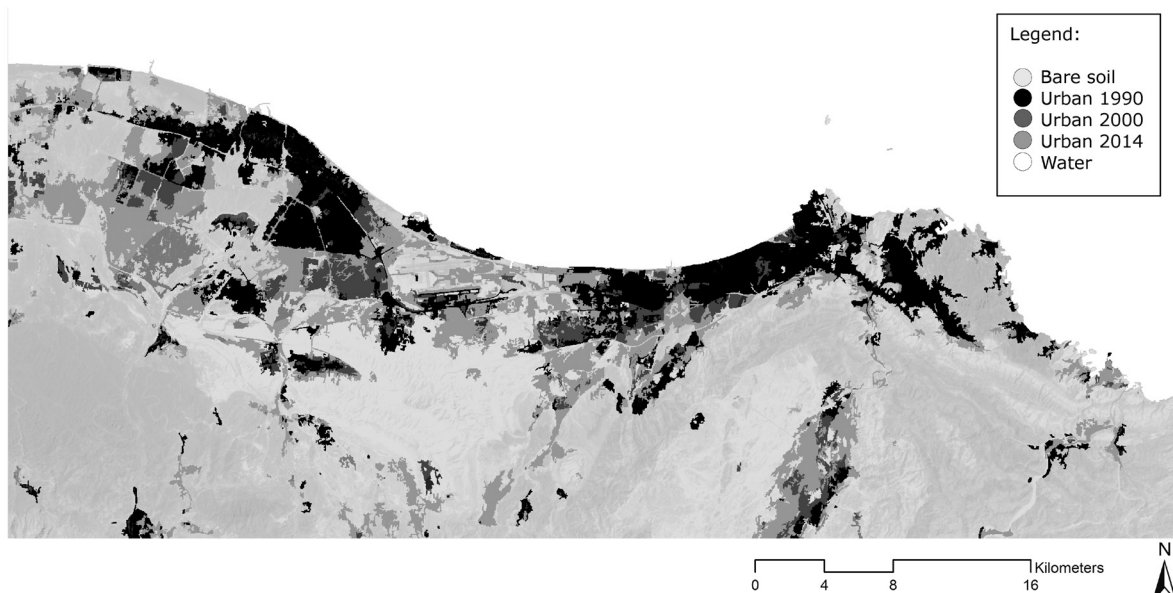


Figure 2: Spatio-temporal map of the urbanised regions (UR) of the MCA 1984-2014

of this development, such as tracing the disappearance of the old town and the changes in oasis settlements and agriculture. The work of Fred Scholz remains the benchmark for the earlier phase of urbanisation until 1990 (Scholz 1990). As he himself was retracing lost parts of the earliest phase of modernisation, from the 1970s to 80s, his laborious work was not continued into the next phase, which was marked by an ever-faster and intricate development starting in the 1990s. As a result, there is neither a quantifiable assessment of the historic and geographic development from 1970 to date, nor a base to derive the trends and limits of future urbanisation. In 2014, more than 85% of the Omani population was living in urbanised regions, primarily concentrated in the MCA.

The aim of this study is to create and analyse a set of spatio-temporal maps of the urbanised regions in the MCA (Bhatta 2010). LANDSAT imagery is freely available and covers the time period under scrutiny, as it reaches back to 1984.

The classification of satellite imagery is usually based on the reflection values of pixels. The different values in the respective bands can indicate specific land uses. Six bands were used in this project. OBIA segments and generates objects from groups of pixels based on parameters such as the homogeneity of spectral values, the shape of objects, the compactness, etc. (Rezaeian and Gruen 2011). Using OBIA methods, it is possible to detect larger houses and areas with a high density of built-up surface and combine them to larger objects by using the relative size of the area. A major challenge, given the desert environment of Muscat, was to find an accurate combination of reflective indices that can distinguish a dust-covered building from open soil.

The reflective evaluation starts with the latest image (2014). The subsequent classifications are, in turn, based on the results of the previous image, working back in time. The hypothesis is that there was no negative growth in the study area during the whole time period, and that we can start from the present to reconstruct the past (Al-Hathloul and Edadan 1993). This method improves the classification quality of older scenes since it excludes certain areas.

Since an urban area is not just buildings but also the space between those buildings, and due to the fact that not all buildings are detectable due to the resolution of the satellite imagery, a method that works with image-object rather than single pixels proved to be the most adequate. At this point it is important to say that this method cannot deliver exact, quantifiable results. However, the results are suitable for visual and qualitative interpretation, as well as relative comparison, since their inherent data structure is consistent. Moreover, the resulting maps have a resolution that historic diagrams could never achieve. To make assumptions about the robustness and the transferability of the method, further research in other study areas is planned. For this project, an accuracy assessment has been a challenge due to the lack of validated reference data. We compared the results to a dataset of manually delineated buildings of the study area. These buildings were traced manually by students of the German University of Technology (GUTech), with an overall accuracy of 70%, during a seminar held by the author.

Evaluating the urban development of the MCA

In order to evaluate the urban development from 1984 onwards, we established two spatial categories: Urbanised Regions (UR) at a larger scale encompassing buildings, roads and otherwise urbanised areas; and Built-up Areas (BU) at a smaller scale encompassing building footprints. We use UR to describe the planar expansion of the city, and the quotient of BU/UR to establish the local density within the city. The spatio-temporal evolution of the UR is described in figure 2. Figure 3 shows the local density of the MCA for 2014. Finally, the development of the UR is quantitatively described in figure 5 for each time frame, and in figure 6 for each "wilayah" (administrative division).

The spatio-temporal description necessitates a closer look at the various time stamps. It is understood that Muscat and the adjacent port towns, villages, and oasis settlements formed the core of the urban expansion after 1970 (Scholz 1990). While the twin cities of Muscat and Mutrah covered barely 10 km² intramural, more than 50 settlements can be counted on a Soviet army map based on Zenit satellite data from 1970 (Muscat, East Batinah Coast

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Table 1: Urbanisation rates by wilayah and for the MCA, by the author

	Mutrah	Bowsher	As Seeb	Al Amrat	MCA
UR rate in 2014	77.7%	74.1%	49.6%	34.1%	53.5%
Date of reaching 50% UR rate	1984	1998	2014	ca. 2018	2012
Contribution to total area of the MCA	8%	21%	44%	27%	100%
Un-developable area of each wilayah	3/4	1/2	1/3	2/3	1/3
Contribution to overall UR rate of MCA 2014	4.7%	21.0%	57.0%	17.0%	100%
Annual growth rate 1984-2014	0.76%	1.53%	1.03%	0.93%	1.09%
Peak growth rate, decade	1.2%, 94-04	1.9%, 04-14	1.7%, 04-14	1.7%, 04-14	1.65%, 04-14

1970). By 1984, the UR accounted for 18.9% of the total land in the study area. The urban form can be described as patches with very loose edges — indicating continuous and rapid growth. The larger urban geometry follows the topographic constraints of the Indian Ocean in the north and mountain ranges in the south. This is also reflected in the city's infrastructure of highways and the airport, which run parallel to the coastline and the mountains.

By 1991, the UR of the MCA had grown to 25.6%. Fjord-like fringes in the east indicate that the city literally washed upon the steep mountains slopes, reaching a maximum in this area. Development in the west of the MCA was mostly around the old port towns and oasis settlements. We see stagnation in urban expansion during the 1990s, due to the slow implementation of the first Regional Structure Plan in 1991 by Weidleplan and an economic downturn during the aftermath of an oil-price drop in 1986 (The History of Oil & Gas Sector in Oman 2014). Back then, as today, Oman was largely dependent on income generated from oil exports to finance its public infrastructure (Al Gharibi 2010).

By 2002, the UR covers 33.7%. For the first time, both centres described by Weidleplan in the east and west merge into one expansion area. Close examination reveals that density was much lower in the newly developed sectors than in the older parts in the east. Finally, the UR reached 53.2% in 2014, representing more than half of the urbanised MCA. Urbanisation has become more asymmetric, with eastern wilayahs stagnating. The costs of urbanisation are exploding alongside the expanses of area requiring by roads, electricity, water and sewerage. An

extrapolation of the urbanisation trend indicates that the MCA will reach its limits, with 80% urbanisation of its developable land and an estimated population of 4.5 million inhabitants, by 2030.

The four wilayahs of the MCA examined here differ in size. Some areas are un-developable due to their topography. Hence, the contribution of each district towards the overall urban expansion differs significantly, as can be seen in the table below. Crossing of 50% UR is a significant threshold for urbanising areas. This event occurred at different moments for each wilayah, reflecting the urbanisation trend from Mutrah to Seeb along the Batinah coast. The overall urbanisation of the MCA crossed the 50% line in 2012. The average annual growth rates per wilayah range between 0.76% and 1.53%, with peak growth rates of 1.9% in the last decade indicating an accelerated, consistently high urban growth. There is hardly any space left to expand in Mutrah and Bowsher. Al Amrat will not be able to accommodate many new houses in the future either, due to its terrain. As Seeb stands out as the area with the largest land reserve, yet it is located on the western side of the MCA, bordering the Al Batinah coastal plain. The continuation of urbanisation along the coast is anticipated outside of the MCA in Barka and Sohar, further north-west.

Urban density maps for the MCA

The density maps measured by quotient of BU/UR indicate the density of the urban expansion and qualify Muscat's urban sprawl. It is important to note that these density maps measure only 2D information and do not

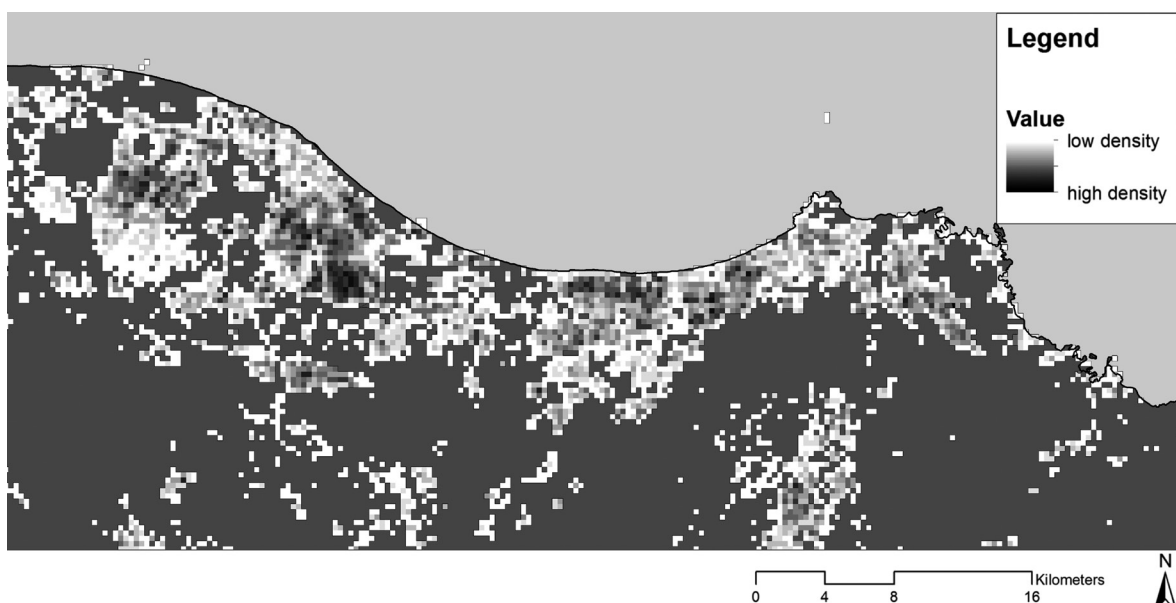


Figure 3: Density map of the MCA, 2014

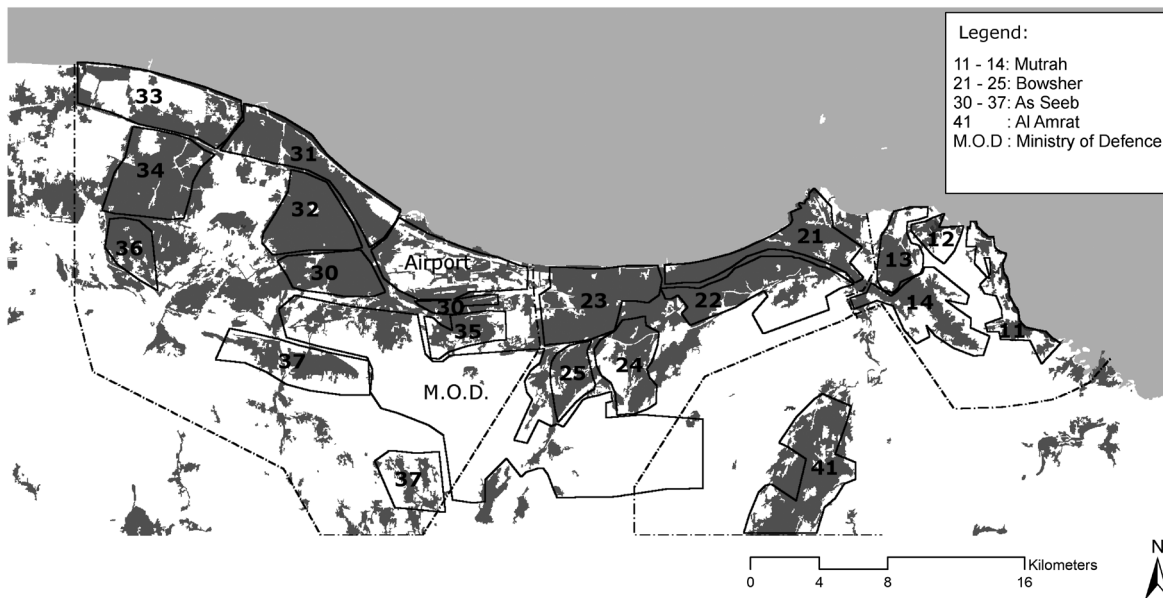


Figure 4: Weidleplan Structure Plan of projected land use in 2010 over actual land use derived from OBIA 2014

contain information on floor areas commonly used to determine Floor-Area Ratios (FAR) — also known as architectural density. Our 2D density can also be correlated to social, economic, ecological or political sustainability (Bontenbal and van Esch 2012).

Density is an additional qualification parameter of urban-expansion phenomena. A denser settlement is related to more-efficient land use and the provision of infrastructure resources. The acceleration (change in time) of densification is an indicator of the efficiency of the urbanisation process altogether.

The patterns visible in the density maps can be split in two phases: the first phase, from the 1980s to the end of the 1990s, is characterised by dense and radiating coastal nuclei; the second phase, initiated in the early 2000s, shows that newer settlements appear in the west and south as well as around the prevailing coastal nuclei. By 2014, these form denser islands in a territory undergoing massive urbanisation. This densification phase is characterised by urban expansion at the district scale. The UR reached a different scale and speed at the expense of land use and infrastructure demand. The western area alone measures 25 km in diameter and has a low average land occupation.

The urban expansion and density maps can be compared to the stated aims of the Weidleplan Structure Plan. The planners recommended, in 1991, that “the [...] ‘twin-city approach’ to the growth of the Muscat Area [shall be] the basic concept for the three strategies laid down in the regional plan” (Weidleplan 1991). This “twin-city approach” intended for the equal expansion of greater Mutrah in the east and As Seeb in the west. The rationale behind this strategy was to control urban development in the already-developed sectors in the east, and to keep land reserves between the eastern and western sectors. The plan also recommended a phasing of sectorial development according to a cost/efficiency calculation. A mix of governmental incentives, such as land allocation to citizens and relocation of governmental bodies as well as restrictions on land development in other areas, was seen as sufficient mechanisms. Limiting urban development in central areas did not take into account that these areas belonged to influential tribes and also proved very

lucrative to develop. The “concentration” of infrastructure investments in remote areas proved expensive and slow. To date, the massive land allocation in the western areas on virtually desert ground has not been matched by the provision of working spaces and commercial and social facilities. Today, these areas form extensive, desolate suburbs. Weidleplan’s desire to create a synthetic solution for the MCA stands out as a major component and weakness of the plan at the same time. The reality of dynamic urban growth, uncoordinated development, and conflicting interests has rendered a “fixed” structure plan like that of Weidleplan redundant. Moreover, the Weidleplan framework can be read as a blueprint for land speculation and expensive infrastructure construction, the exact opposite of the intended resourceful urban development. The plan’s time horizon of 20 years, until 2010, is a further weakness, at least since it was never updated or adjusted. The plan does not investigate the limits of spatial growth, nor offer a strategy on how to address the depleting spatial resources of the MCA.

Assessing “peak space” for the Muscat Capital Area

We propose to evaluate spatial expansion with constraining factors in order to establish the limits of the MCA’s growth. Natural features — in particular the topography, coastline, and wadis — posed constraints to the form and speed of urbanisation early on. As a result, the “natural” imprint of the maximum urbanisation forms a specific urbanisation basin, one that is fragmented and fjord-like in the east and that gradually washes into the gravel plains of the west. Urbanisation also depends on the development of man-made infrastructure such as roads, retention dams, ports, airports, desalination plants, etc. to connect the fragmented urbanisation basins of the MCA (Diener, Meili, and Jovanovic 2013). This infrastructure acts as a development corridor for urbanisation, one with a certain impact radius. The radius of impact changes over time. Until the 1990s, urbanised areas affected adjacent areas within a radius of less than 5 km. Since the 2000s, this radius has expanded to 25 km, as measured in figure 2, and with it the time spent in traffic by Muscat’s citizens as well. Urbanisation also has social limits, if certain parts become inaccessible and segregated by the urban morphology. The correlation of urbanised land to census data

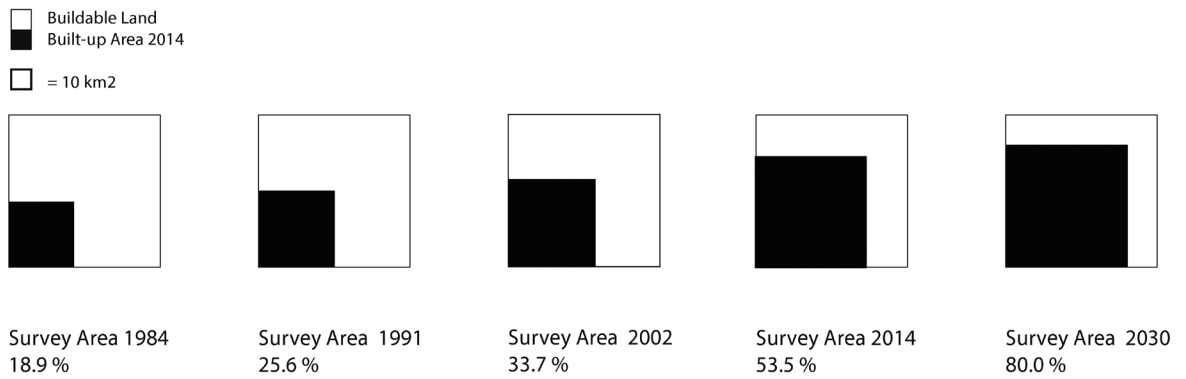
Aurel von Richthofen

is an architect and researcher at the Future Cities Laboratory in Singapore (FCL) affiliated to ETH Zurich where he leads a research module developing sustainable building materials and researches on sustainable urbanisation in emerging societies. Prior to Singapore, Aurel spent four years teaching architecture at the German University of Technology in Oman (GUtech). During this time he was co-investigator on a research project on sustainable urbanisation patterns in Oman - sponsored by the Research Council Oman. Contact: vonrichthofen@arch.ethz.ch

Sebastian Langer

is currently MSc Candidate for Applied Geoinformatics at the Department of Geoinformatics “Z-GIS” at Paris Lodron University of Salzburg. During his studies he did a 5 months internship at the German University of Technology in Oman (GUtech) at the Department of Sustainable Tourism and Regional Development. A focus on OBIA-methods and the experiences in Oman were the main motivators for this work. Contact: sebastian.langer@stud.sbg.ac.at.

Figure 5: Built-up area in the MCA, 1984-2014



shows that demographic pressure is a main driver of urbanisation. While the population is still rising, the amount of space is gradually decreasing, and the urbanisation curve of the MCA will reach a saturation level of 80% within the near future. Furthermore, the ecological footprint in Oman is growing rapidly. The per capita consumption of electricity in Oman shows that the Omani population, and the inhabitants of the MCA in particular, use resources excessively. In other words, a sustainable urban expansion needs to take ecological considerations more seriously. The concept of peak oil (Hubbert 1949, Wiedmann 2010) describes the production of a finite resource under market mechanisms. It is helpful to analyse the pivotal moment (peak) in the consumption of resources, and to determine the speed (saturation) of the depletion of this resource. The transfer of this concept onto space is based on the following assumption: while land is finite in its expansion on the surface of the globe, it can be used both simultaneously for various purposes and successively in time and therefore cannot qualify as truly exhaustible. Nonetheless, the transformation of open land into urban space usually goes hand-in-hand with a heavy financial investment and altered soil composition, and materialises in the form of buildings and infrastructures that are resistant to change. Therefore, the production of urban space is an irreversible process and depletes open land resources. While the FAR can be increased locally on a given plot by architectural additions, changing the overall FAR in a built urban fabric is very difficult. It is assumed that urban space in function of density engrained in the urban development strategy is also finite. In Oman, barely 3% of the nation's land can be used for agriculture, which co-relates to the space available for sustainable urbanisation (Zekri et al. 2010). The concept of peak space takes

the variability of the overall spatial resource into account as new technologies and energetic expenses change. The natural and man-made constraints can be drawn on the physical map of the MCA and overlapped with the derived UR. Figures 5 and 6 record the development of the BU from 1984 to 2014 in the study area. In projection of this trend, 80% of the available land will be used up by 2030, representing a level of saturation that makes further development of urban space very costly. Since Muscat is the capital of Oman, economic and demographic development is likely to continue beyond 2030. The effort to create and develop secondary cities further south and inland will offer no relief from running out of space in the MCA. The establishment of the peak-space moment can help the public sector to orchestrate all present and future efforts in light of depleting spatial resources. Currently, the provision of infrastructure and buildable land are not synchronised, as figure 2 underscores. As a starting point, the allocation of buildable land could be changed towards the allocation of residential space. The present FAR for residential plots is very low, as a result of free-standing villas. The density calculated for the urban expanse is even lower. The same amount of residential space could be allocated on much smaller plots. Re-densification will require changes in the physical planning standard and zoning of the MCA. Furthermore, adaptation of the building code is necessary to account for alternative building typologies. All these changes, including new forms of financing and taxation, will require public debate. The public and media in Oman need to discuss a common approach to less land-consuming forms of urbanisation. It is crucial for the public to understand that land is a precious and scarce commodity, albeit the free governmental land allocation.

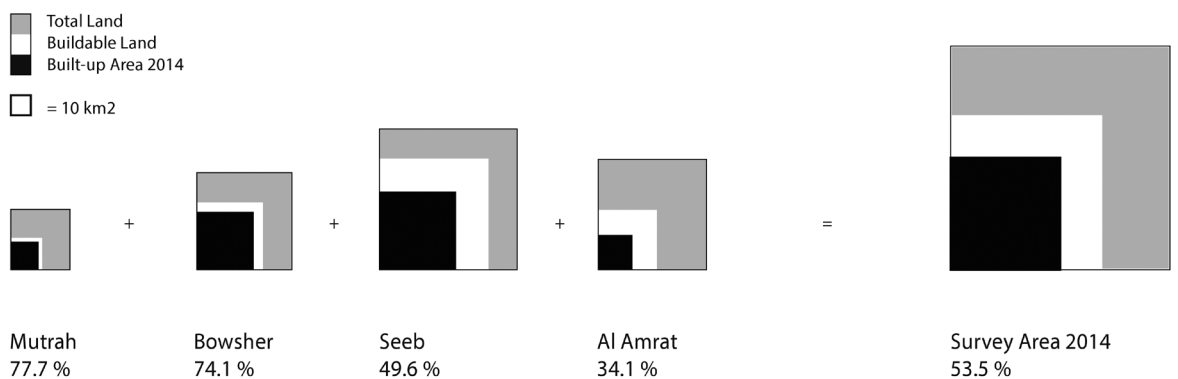


Figure 6: Built-up area per wilayah in the MCA, 2014