Dangerous development on dolomite: considering the spatial distribution of low–income human settlements in the Gauteng City Region

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Abstract

Ground underlain by dolomite may be hazardous to development due to the potential occurrence of subsidence and sinkholes. These potentially disastrous occurrences are caused by an interaction between soil and moisture, through for example the ponding of water or leaking of wet infrastructure such as water and sanitation services. Construction materials and techniques, as well as effective maintenance of waterborne services have traditionally been acknowledged as having a significant bearing on the level of risk that communities face when living on such potentially dangerous land.

The spatial distribution of settlements on dolomite in the Gauteng city region is already widespread and expected to increase as urbanisation intensifies. Similarly, the challenge of considering the physical vulnerability of low-income settlements is expected to intensify. Well-defined procedures and guidelines govern the development of human settlements on dolomitic ground. However, the classification and characterisation of low-income and informal settlements over the spatial domain are not as advanced as that of formal residential developments. In addition, the guidelines regarding management of settlements on dolomite focus significantly on geotechnical interventions, leaving a gap in the influence that human behaviour can play in possible disaster risk reduction on such ground.

The paper focuses on the consideration of the spatial distribution and settlement type characterisation based on spatial layout and dwelling types for various low-income settlement types found on dolomite in Gauteng and surrounding areas (the Gauteng city region). Settlement types that were considered, based on aerial photography, cadastral information and field verification include informal settlements, formal housing with backyard structures, state-subsidised and low-income bonded housing. The research hypothesises that an understanding of settlement type among other elements, could address some of the conflicts in the development-on-dolomite debate and thereby reduce settlement vulnerability. It is not possible to present all the contents and outcomes of the doctorate thesis which the paper is based on, therefore the paper focuses only on the spatial and settlement characterisation component of the thesis analysis and the related outcomes of the research with regard to settlement characterisation.

Keywords
dolomite, disaster risk reduction, physical vulnerability, low-income settlements, settlement types, services delivery, dwellings

Introduction

The integration of economic growth and functional urban form often create turmoil among governments, public and private sector role players, academic disciplines, planners and communities alike [33]. The situation is further hampered by climate change challenges, community behavioural anomalies, a lack of awareness or integration of knowledge, and resource limitations [13]. This means that even when features such as settlement types are characterised, it remains to a large extent a theoretical process which does not always correspond to real-world scenarios. With the increasingly urbanised human settlement landscape, responses to the need for urban development solutions are often fast-tracked and if not carefully considered, resulting in communities becoming progressively vulnerable in their physical surroundings [45]. Settlement typology and settlement characterisation have taken various forms in the past, but the lower end of the economic spectrum remains poorly investigated. This paper considers, in particular, low-income settlements that range from small bonded houses to Reconstruction and Development Programme (RDP)-type settlements, backyard dwellings and informal settlements in the Gauteng city region (GCR), in the context of its location on dolomite as particularly hazardous ground.

Karst landscapes form due to the presence of highly weatherable dolomite or limestone. The older these formations are in geological age, the more prone they are to weathering. Dolomite is particularly prevalent in the GCR and represent some of the oldest and most weathered karst landscapes on earth [7]. Ground underlain by dolomite is hazardous due to the potential occurrence of subsidence (dolines) and sinkholes [11]. These potentially disastrous occurrences of sinking ground are affected and most often caused by human-induced changes in soil moisture content, for example due to water ponding or leaking water-bearing infrastructure [23].
Therefore, conditions of development, construction techniques and maintenance of wet infrastructure have a significant bearing on the level of risk that communities face when living on such land.

The original urban areas in and around Gauteng were less constrained than today’s urban expanse by the hazards that dolomite present. The GCR is experiencing unrelenting urban development, expansion and settlement densification. Inadvertently, the situation has placed urban development in close presence of the dolomitic hazardous ground. Fig. 1 presents the formal urban areas, informal settlements and the “ring of dolomite” in Gauteng.

![Fig. 1: Urban land cover, informal settlements and dolomitic ground in Gauteng [15].](image)

Varying characteristics of dolomite determine the level of hazard in relation to human settlements [12]. These characteristics include, among others, the underground structure, the age and make-up of geological strata, the depth at which it occurs, as well as the type and thickness of the overburden (soil covering the strata). The uneven distribution of dolomite patterns across often small spatial expanses, coupled with undeterminable directionality, shape and size of underground caverns causes difficulty to determine an absolute risk level in many areas. Regulations, national standards and guidelines pertaining to development on dolomite therefore consider relatively conservative options for development on inherently hazardous ground.

Development often avoids karst ground, the preference being to set it aside for parks or ecosystem services [14]. Even though such avoidance remains ideal, reality shows that the intention of greenbelt restrictions often gives way to urban development pressures [47]. Where development does occur, building regulations, restrictions and planning processes are largely involved [39]. Gauteng experiences a critical juncture between densely populated human settlements and significantly high dolomite hazard levels. In order to address the development-on-dolomite issue, South Africa has since the 1970s designed, refined and implemented pre-development assessment and reporting procedures, national standards, building regulations and guidelines. Examples of formally approved development on dolomite in Gauteng include Lenasia [25], Centurion [28], and the Gautrain rail alignment [18]. By 2001, at least 270 000 formally approved dwelling units (including subsidised low-cost housing) in the province had already been built on dolomitic ground, while between 2001 and 2009, at least another 55 500 new residences were added to this number, on dolomite of varying hazard levels [15]. The 2011 South African census data reveals 305 682 households living in informal backyard structures in Gauteng [44]. Fig. 2 shows the proliferation of backyard structures in Gauteng with the count amounting to at least 727 740 – more than twice that of the Census count.
The definition of the categories of formal development types on dolomite did not foresee the proliferation of indeterminate settlement configurations which include informally constructed dwellings and un-registered backyard units not approved or registered via formal municipal processes [17]. Recent amendments and additions to development on dolomite standards [43] address some of the elements of informality and regulate through intensive site investigation. However, the classification of low-income settlement types remain a challenge.

**Low-income settlement type classification challenges**

In Gauteng’s urban areas, the proportion of settlements that intersect with hazardous dolomite is increasing in parallel with the progression of settlement densification. Where large quantities of individuals and households with relatively low-incomes settle in or near these dolomitic-underlain urban areas, the disaster risk is considered to increase dramatically [23]. “Low-income” in the context of this paper is a relative concept that refers to the general income in an area in relation to the household size. Placing a monetary value on the concept is challenging. However, in general household incomes in these so-called “low-income” settlements would range between zero and R100 000 per annum for a four-member household. Dwellings associated with these areas are generally no larger than 100 m².

Figs. 1 and 2 shows the proliferation of informal and backyard dwellings in settlements such as Thembelihle, Protea South, Bapsfontein, Winnie Mandela Park, Khutsong, Thusong and Ivory Park, being located close to, partly or entirely on dolomite. Protea South remains engaged in legal processes to determine their future, with possible relocation to an area called Doornfontein. The Bapsfontein settlement was relocated to a site 30 km away from its original placement, while Winnie Mandela Park was an informal settlement that was developed cautiously and taking into account geotechnical engineering requirements, despite being underlain by dolomite. Khutsong and Thusong are in various stages of development and provision of services, while some areas are being relocated based on dolomite hazard levels. Ivory Park was partly developed as serviced sites pre-1994 without clear guidelines regarding how dwellings would be constructed on the dolomite, while a more recent housing project approximately ten years ago implemented dolomite-approved raft foundations [46].

With regard to vulnerability on dolomitic ground, medium to large dwelling units with foundations of on average 170 m² or larger [22], constructed from brick and mortar with formally designed water-bearing infrastructure, dominate South African residential geotechnical solutions. Few of these characteristics are relevant to low-income settlement types, where structures are small and often informally built and basic services are lacking or provided after initial development took place. Only one study thus far investigated the context of low-income settlements on dolomite in South Africa [6]. There is agreement among technical sciences that it is possible, under certain circumstances, when following prescribed procedures and grey or traditional infrastructure interventions to develop on dolomite. These interventions vary depending on differences in settlement characteristics primarily related to development density. However, since low-income settlements do not conform to formal settlement characteristics and there is varying dwelling density due to its informally developed origins, decision making regarding low-income settlement upgrading on dolomite faces a complex
challenge where investigations have to be conducted after settlement establishment. Although guidelines such as the Red Book [8] exist, the development or upgrading of low-income settlements on dolomite ground remain un-nuanced. The South African guidelines with respect to density of residential development on dolomite to a large extent do not accommodate low-income settlements. Residential types are referred to in terms of gentleman’s estates, residential type 1, 2 and 3 (as per town planning terminology), and “affordable housing”. Stand sizes of 300 to 1000 m² consider largely single dwellings on stands and not where for example hundreds of informal dwellings could exist on large non-proclaimed spaces. The affordable housing type considers one dwelling per 300 m² stand or larger, thus excluding many low-income settlements.

Scientific research regarding settlement infrastructure development on dolomite is widespread [3, 5, 41]. However, these research outputs do not consider small sized dwellings that exist in low-income settlements. Kirsten et al. [22] proposed a method to consider dwelling risk exposure on dolomite, based on individual dwelling characteristics and assuming the size of a dwelling to be at least 13 m x 13 m (much larger than the average informal dwelling). Their method for risk assessment is useful to consider safety risk to the inhabitants of a dwelling and could be adapted to smaller dwellings. A unit density limitation also remains, since dwelling density in in low-income settlements is usually significantly higher than what is covered in SANS 1936 [42, 43].

**Classifying low-income settlement characteristics**

Huchzermeyer, Karam and Maina [21] investigated informal settlement forms in Johannesburg using GIS and satellite imagery. Among other things, they found that vector-based spatial data, aerial photography, satellite image interpretation and catalogued databases of informal settlements show significant differences in the way in which such settlements are identified and treated from a developmental perspective. This alludes to not only the important role of timely and accurate data, but also the methods of analysis or interpretation of raw data, thus metadata. Often, by the time that development decisions are made or upgrading is due to take place, settlements may not have the same spatial layout, extent or dwelling types as was present when data collection and image analysis which informed the process was done [21]. Thus, settlement studies based on spatial data or municipal databases from even a year or two before studies are completed, may not be valid unless field investigations and adjustments are made based on ground-truthing shortly before the development or upgrading begins. In response to this situation and with input from the National Upgrading Support Programme [32], the City of Johannesburg (CoJ) has changed its methods of engagement with informal settlements to ensure that development and upgrading is relevant by the time that it commences.

International research regarding low-income settlement types place a significant focus on the location-based component such settlements [2]. However, the physical characteristics of settlements in relation to location-based vulnerability have been less explored [34]. The key elements of settlement type consideration for physical vulnerability assessment appear to include at least dwelling type and average settlement density [9, 38]. In this context, dwelling type commonly refers to individual dwelling units that may differ in form, construction method and fabrication materials. Density considers the size of units in relation to stands, as well as distance between units, thus translating into a percentage difference between built-up ground surfaces vs. that which is left open.

Settlement studies are commonly based on theoretical exploration that has a spatial and practical component [26]. Settlement classification systems follow this trend and rely significantly on spatial density classification via the use of cartographic maps, aerial imagery and remote sensing [27]. Using such data, the South African Human Settlements Atlas [9] provide settlement categories that relate to development potential. Density considerations from the atlas relevant to low-income settlements in the context of dolomite hazards include areas of very low, low and medium density. These three categories cover single detached units that may include government-subsidised or privately funded dwellings, single detached units with backyard dwellings, semi-detached units such as duet houses and detached duplexes and cluster housing such as townhouse complexes, detached triplexes and low-rise apartments, all which have a wide array of tenure types [9]. In another vein, Glass, Morkel and Bangay [20] explored informal settlement layout patterns in settlements using aerial photography and satellite imagery, combined with procedural techniques. Their assessment focussed on spatial classification of some of the typical informal settlement layouts in South Africa, in accordance with geographical modelling processes. They proved that it is possible to generate graphical settlement layout models and digitally simulate some of the patterns found in informal settlements, classifying informal settlements into clusters (types). Their study provides insight into the spatial form of low-income settlements and the manner in which dwelling density can be considered when using aerial photography. Finally, an example of a “toolkit” for settlement type assessment, was produced through collaboration between the Human Sciences Research Council (HSRC), CSIR and Department of Science and Technology (DST) [10]. Their settlement survey classification aims at “effective spatial planning at municipal level” [10: 7] and identification methods are suitable for
differentiating the variety of settlements that exist throughout the country based on service delivery and economic elements as well as the density of dwellings. Even though the study was in-depth and may be applicable to the low-income settlement investigation, it does not consider the potentially hazardous ground on which some settlements are built, as a reason for differentiating between settlement forms.

**Low-income settlement consideration on dolomite**

The situation that exists with regard to settlement classification makes the provision of basic waterborne infrastructure to low-income communities a highly contested arena as a number of court cases have shown [29 – 31, 35 – 37]. In the struggle for legitimisation of settlements on dolomitic ground, opposing parties tend to argue their case from dissenting platforms that do not consider settlement typology. For example, the Bill of Rights [40] opposes Geotechnical regulations [42, 43] regardless of settlement type.

The settlement type identification presented in this paper considers spatial identification and delineation of settlements based on dolomitic ground and the visibility of dwellings of a similar density within an 1km x 1km vertical aerial radius. The process employed the use of GIS software, including distance measuring between units and features visible on digital maps. This selection was deliberate to allow an attempt at settlement type classification on dolomite. High-resolution aerial photography (2.5 m x 2.5 m) and satellite images were employed to do visual spatial delineation. Sample settlement locations considered for this paper are presented in Fig. 3.

![Fig. 3: Locations of research sample sites on dolomite across Gauteng.](image)

For this purpose, settlement density considers the spaces between dwellings, regardless of occupancy and formal or informal road or pathway existence, or the presence of servitudes. Dwelling refers to the unit of residence (excluding outbuildings, lapas (roofed recreation areas), sanitation amenities and/or cooking facilities). Where backyard dwellings exist, such buildings were treated as individual dwelling units, where it could be distinguished. It may not always be possible to distinguish the difference between outbuildings used as residential units vs. those used for storage purposes or as garages without detailed individual stand investigations. Where such features were identified using spatial data, the real-world situations were verified by means of multiple random physical street-view spot-checks in the selected areas. The density classification for settlement types for purposes of this study was established by considering the average distances between units in meters, across a roughly square 250 m² area in the settlements, in areas where it was possible to identify relatively uniform spatial layouts. After the field visits, information collected from the sample sites was compared and common characteristics in relation to settlement vulnerability on dolomitic ground identified. Dwelling density, building material use and layout types were also considered. The analysis and characterisation enabled the categorisation of low-income settlement types for the research analysis phase into ten distinct types.

**Low-income settlement types defined**

*Understanding low-income dwellings*

The most basic scenario of low-income settlements and informally built dwellings is that they house the poorest of the poor communities. These settlements are constructed usually without permission to do so, on open ground – such land usually being owned by the state or municipality and zoned for a purpose other than residential. A next tier of dwelling type may be constructed using informal and recycled building materials and construction
methods, on ground allocated to the occupants by means of an informal lease or rental arrangement with the landowner. In this case, private landowners may make parcels of land available for informal settlement development for commercial gain. It is also common for informal dwellings to be managed by a “shack lord”, who, without having a legal right to the land, rents out sub-standard or temporarily constructed dwelling units.

Beneficiaries of subsidy-funded housing may remain in informal settlements while awaiting access to formal lodging. Alternatively, during this pro tem time, a stand or erf may be allocated to them in which case informality often emerges. Where stands are allocated and informal dwellings constructed, the informal dwellings in some cases remain after construction of the formal subsidised top structure. After construction of subsidy-funded housing, additional dwelling units may be constructed, thereby increasing the originally planned dwelling and occupation density of the area. An example is visible in Fig. 4, where subsidy-funded housing, brick-and-mortar backyard units (under construction), and dwellings built from metal and wood sheeting is visible, all on a stand which was originally intended (and registered) for only one dwelling unit. Fig. 5 shows another example of a mixture of construction materials and -methods on formally delineated stands.

![Formally constructed housing with informal backyard units (Winnie Mandela Park)](image_url_4)

*Fig. 4: Formally constructed housing with informal backyard units (Winnie Mandela Park)* [16].

![A mix of formal and informal dwellings on formally serviced sites (Olifantsfontein)](image_url_5)

*Fig. 5: A mix of formal and informal dwellings on formally serviced sites (Olifantsfontein)* [16].

The level of informality associated with the construction methods and materials, and the associated type or lack of wet infrastructure poses a potential threat when these forms of development intersect with dolomitic ground. Wet infrastructure service delivery to these units is either in the form of stand-piped water (i.e. a water tap every 100 to 200 m), usually with no grey water drainage provided, and a combination of communal and individual sanitation. Where stand pipes and taps leak or where sanitation infrastructure is leaking or is inappropriate to development on dolomite, the dissolution of subsurface geologic strata may occur.

The uppermost tier in the low-income range of settlements considered in this paper is bank-guaranteed, privately funded and commercially constructed housing. This usually takes the form of fairly small (approximately 100 m²) dwelling units on separate stands, with shared foundations, walk-up apartments, blocks of flats, or
otherwise associated or connected units in a sectional title or building association format. The latter types are often in the form of gated complexes or estates, meaning that some collective decision making on maintenance expenditure takes place. In the above-mentioned dwelling and settlement types, rules regarding occupancy, changes to building facades, and construction of structures on common property are strict, thereby ensuring a high level of formality associated with such developments.

Although the sampled settlements on dolomite in Gauteng display the observed range of characteristics described hereto, the settlement types are not mutually exclusive and different dwelling material and construction types are often found in a mixed fashion in close proximity to one another. Therefore, decision making in the national, provincial or municipal sphere regarding the development or upgrading of low-income settlements on dolomite is riddled with difficulties when attempts are made to apply dolomite-specific building regulations and guidelines intended for formally approved settlement forms to the low-income domain.

The form and function of government-funded housing in South Africa have remained much the same over the past two decades. The standard layout consists of individual stands, each with a freestanding house of a current minimum size of 42 m² (before this minimum was introduced in 2000, dwellings were often smaller). The row-upon-row of small freestanding houses leaves little space for deviation from the predefined form. As opposed to single stands with small freestanding houses, walk-up apartments and row housing have been considered and implemented in a minority of locations. However, in the context of so-called RDP or BNG projects these forms are considered “alternative” and remains implemented in limited selected locations.

Defining low-income dolomite settlement types

Settlement types for purposes of this paper consider density, dwelling type as it relates to building materials, and wet services infrastructure type and configuration. The dwelling density considerations and information gathered from field visits related to building materials and wet services enabled the development of settlement type classification on dolomite (Table 1). The settlement types are grouped into six classes, (A to F), with descriptions of each class according to characteristics that were most prevalent during field observations. Figs. 6 to 15 graphically depict the characteristics of each type that was defined.

Table 1: Settlement types identified and described in this paper

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description of dwellings commonly found in this type</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Shacks</td>
<td>Small dwellings constructed from wood, cardboard, metal sheets or plastic. Floors are usually covered with soil, dung, wood or cardboard (sometimes later replaced with concrete).</td>
</tr>
<tr>
<td>B</td>
<td>Informal (not approved by municipality, not compliant with building regulations)</td>
<td>Dwellings of roughly the same size as Type A, but with dwellings constructed of cement bricks, and usually second-hand brick-and-mortar randomly spaced throughout the settlement.</td>
</tr>
<tr>
<td>C</td>
<td>Low-cost formal housing</td>
<td>RDP-type dwellings, part- and privately mortgaged/bank-guaranteed (in South Africa also referred to as ‘bonded’) residences, where individual stands/erfs can be clearly recognised, and formally constructed out of cement, brick and mortar. Dwelling sizes generally remain small.</td>
</tr>
<tr>
<td>D</td>
<td>Low-cost formal housing with backyard units</td>
<td>Similar dwelling size as Type C but with informally constructed dwellings on the formal stands in addition to formal low-income housing. This differs from Type B which also has dwellings in the settlement constructed out of brick and mortar, in that Type D has a formal and more regular layout, based on formal planning design and usually infrastructure and basic services having been provided.</td>
</tr>
<tr>
<td>E</td>
<td>Row or attached units on common raft foundations</td>
<td>These types provide opportunity for the same or slightly higher population densities than Types A to D, but with increased stability on dolomite (depending on the specific hazard level of the dolomite in a given location). Historically, before dolomite building regulations and standards were rigorously applied, these dwelling types shared foundations that were normal to all dwellings whether they were on dolomite or not – the concept of raft foundations was only introduced after the 1970s. The average height of these units range between two and four storeys.</td>
</tr>
<tr>
<td>F</td>
<td>Apartments and high-rise flats (more than four storeys without an elevator; or whichever building regulations permit in a given municipality)</td>
<td>Medium to high density social housing, usually unsuitable for construction on dolomite due to the significant increase in structural weight and construction costs. Recently, a high rise apartment block (with bachelor units selling for prices from just under R500 000 each) was approved and is under construction in Gerhard street, Centurion, Gauteng, on dolomite. However this is not the norm and was thus only included in the early research classification stage since it forms part of low-income housing provision and urban densification strategies worldwide especially on non-dolomitic ground.</td>
</tr>
</tbody>
</table>
Due to the influence that wet services integrity and maintenance has with regard to dolomite risk, the configurations of such infrastructure were included in the delineation of settlement types. In cases of dwellings made of non-durable building materials (Types A and B), it is possible that wet services such as standpipe-supplied potable water and any given form of sanitation services may or may not be present. In some cases, where no potable water is supplied, the residents rely on borehole or river water, or water brought in by vehicles or other means. Therefore, although the presence of wet services is included in the graphic representations, the study recognises that it may be absent. The resultant analysis considers the hypothetical existence of such services, even if it may not currently exist in a given settlement. While individual dwelling sizes may differ from the given descriptions, the average size of dwelling units in the area is considered. The distribution of dwellings may also be more irregular than depicted in the representations.

In the figures hereafter, dwellings depicted in grey with black outline represent those constructed of informal materials such as wood, metal sheets and cardboard. Units depicted in yellow blocks with black outline represent dwellings constructed out of cement bricks, new or re-used brick and mortar or similar materials (considered “more durable” to some extent), regardless of whether it conforms to design or building specifications, building application processes and building regulation requirements. The reason for this undefined specification that treats all brick and mortar buildings as one feature is that the description focuses on spatial density and not on whether the density was achieved via formal or informal processes. Features in brown and outlined in black depict examples of positioning of sanitation units (toilets) in or near dwellings while blue lines and blue cylindrical features present examples of the presence of potable water services (in the form of pipes and taps).

The main difference between Types A (Figs. 6 and 7) and B (Figs. 8 and 9) is that settlements of Type B display a significantly higher proportion of dwellings (estimated 40% or more) constructed from cement, brick and mortar, even though they remain informal in nature.

![Fig. 6: Type A1: Very low to low density, shacks.](image1)

![Fig. 7: Type A2: Low to medium density, shacks.](image2)
Fig. 8: Type B1: Very low to low density, informal dwellings.

Fig. 9: Type B2: Low to medium density, informal dwellings.

Fig. 10: Type C1: Very low to low density, formal housing (including fully or part subsidised housing).
Although Types C1 and C2 both conform to the “low density” classification devised by the CSIR [9], two distinct densities were defined for this study after field visits were done, reflecting the situation that was found in sample settlements, with Type C1 being less densely spaced than C2 (Figs. 10 and 11). Settlement Type D is initially comprised of formal housing, which includes fully subsidised or part subsidised bonded or privately mortgaged housing. This Type may originally have been classified as Type C after initial construction, but due to the emergence of backyard dwellings and shacks in-fill between the free-standing brick and mortar dwellings is now considered Type D. Sanitation could be formal or informal in nature.

Settlement Types E1 and E2 reflect formally constructed dwellings on shared or raft foundations considered suitable when building on dolomite. The reason for including shared non-raft foundations is due to a large number of this type of dwellings that were built during the 1970s and shortly thereafter that did not have raft foundations implemented, but where wider foundations were considered safer options on dolomitic ground at the time. Although these figures depict rectangular layouts, dwelling units with this foundation type may be staggered or diagonally arranged. The stands, when designed for construction on dolomite, conform to the stand size and Du/ha determination as per dolomite hazard investigation requirements. Type E1 reflects predominantly single-storey dwelling units on shared foundations, while Type E2 reflects multiple storey units (up to three storeys high, or depending on what is deemed acceptable for the specific dolomite hazard level as per SABS [43].
Fig. 13: Type E1: Low to medium density, with shared or raft foundations.

Fig. 14: Type E2: Medium density, with shared or raft foundations.

Fig. 15: Type F: Medium to high density, multiple storey and high-rise flats.

The defined settlement types are unlikely to appear in reality exactly as per the graphical representations in Figures 6 to 15 and the descriptions do not cover all possible permutations of actual settlement characteristics. For example, plot and dwelling sizes may vary while the position of wet infrastructure and layout may differ. However, the general combination of features visible from an aerial and in-field perspective assists in categorising each real-world settlement type. Once the settlement types were defined, a process was followed to
determine the relative importance of settlement type sensitivity on dolomite – a process and outcome not described in this paper.

Conclusion

Settlement type identification method using satellite imagery and remote sensing that consider characteristics of land use and land cover are not always replicable when compared to real-world scenarios [4]. Although procedurally generated patterns may reflect real-world archetypes the reality of patterns when based on elements such as density and clustering via aerial view present constraints when applying this approach to especially informal settlement types. Vertical aerial views of settlement layouts do not usually consider variables such as construction materials, structure height, and layout of wet services infrastructure. The boundaries that can be identified from an aerial perspective in informal settlements in particular are not ideally suited to settlement type recognition for determination of suitability on dolomite if not combined with site visits. The building material and weight, foundation type and subsequent ability to withstand ground motion in the form of dolines or sinkholes, as well as wet services materials and condition is of significant importance when determining suitability on dolomite. The classification is even more difficult to do when settlement spatial patterns differ across small geographical areas, for example where settlements are part-formal, part-informal and a combination thereof due to backyard dwelling infill.

Although difficult, it is possible for settlement types to change over time and for these changes to be tracked using aerial photography [1]. Such changes in settlement types are especially where dwellings of the same size and in the same location could change from wooden to metal or brick and mortar, thereby transforming temporary dwellings over time into more permanent structures. In some cases informal settlements may be subject to what is referred to as incremental or roll-over upgrading [24], thereby formalising both the basic municipal services as well as the dwellings. In other instances, informal settlement upgrading may take place through provision of basic services only, without housing interventions by municipalities or their service providers. Where such upgrading takes place, residents may be prompted by their perceived security of tenure to change their dwelling from informally built out of largely non-durable materials (such as wood or metal sheets) into one made of brick and mortar. This challenges settlement characterisation, which forces the characterisation process to be a flexible and fluid one.

While recognising that no two settlements are exactly alike and graphic depictions of layouts fall short of reality, the research ground-truthed settlement types that reflect as close as possible real-world scenarios. Only field verification can confirm differences between settlement characteristics. This makes commercial investigation and classification time-consuming and costly, especially where large expanses of settlements are anatomised. As noted earlier, the danger that dolomite poses to development can be overcome in selected cases via the use of geotechnical interventions and by employing particular, often costly construction materials and methods.

The settlement type selection presented in this paper enables consideration of low-income settlements on dolomite in more detail than previous research done to date. The selection is applicable since it includes the presence of backyard dwellings and small, freestanding houses. The types defined also enables an additional element of variability to be added to the development-on-dolomite guidelines that focuses on consider dwelling units per area [42] in predominantly approved and formalised environments. When considering unit sizes in low-income and especially informal settlements, the existing building requirements and guidelines are not easily transposed or assessed, nor is it possible to accurately predict the level of maintenance of waterborne infrastructure over the long term or the management of backyard dwelling in-fill and subsequent population number increase. The settlement types and criteria selected for my research enables, in addition to known wet infrastructure requirements, issues related to monitoring, maintenance, engagement, ownership and transformation of settlement types over time to be considered.

The importance of appropriate wet services infrastructure, along with the notion that the type of settlement on dolomite does not make a significant impact on the ultimate level of risk supports the notion that it is “not necessary to confine housing strategies to conventional methods and technologies” [8: 2]. This reflection allows consideration for alternative types of dwellings to be constructed on dolomite, as long as the wet services infrastructure provisions are suitable to reducing risk on dolomite. Alternative dwelling materials, other than brick and mortar, including consideration for alternative methods of foundation construction may therefore be an option on dolomitic ground. The need to make “space for incremental upgrading approaches in settlement types to provide sustainable and affordable levels” of basic service delivery “while ensuring acceptable and adequate functionality” [8: 2] could therefore potentially be met by considering a particular community’s understanding of and willingness to live with a certain level of risk, in exchange for having access to other
benefits that the urban environment offers. The results of the research questions the notion of considering non-formal dwelling and settlement types as well as construction materials as unsuitable on dolomite.

Traditionally, wet infrastructure construction on dolomite is treated as being significantly different from “normal” wet infrastructure in geotechnical circles. However, in some cases these differences are not alluded to in housing literature. It is indeed necessary to address the assumption that low-income settlements take similar shapes and forms across geographical spaces in South Africa. Thus, instead of being treated as similar entities with the same characteristics, low-income settlements should be viewed as delineating potentially significantly different settlement types. This recognition will affect budget allocations, housing design, construction interventions, as well as community engagement and public participatory processes when development, upgrading or relocation of settlements is considered. In this form, low-income decision making can promote the pursuit of urban sustainability, even if it means that the time frame for implementation and resources allocated to the process may have to be reconsidered.

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- University of the Witwatersrand, Johannesburg

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