PAPER 14

BIM TECHNOLOGIES FOR INTELLIGENT ROAD STORMWATER DESIGN

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ABSTRACT

Roads form an integral part of Civil Infrastructure, providing safe and reliable access from point of origin to destination. With the rapid growth in population, urbanization, and the pursuit of smart cities, the pressure on effective road design, construction, and maintenance is ever-increasing. With this influx of demand, traditional processes are put under strain, resulting in roads designed inadequately impacting safety and service, with one of these components being stormwater design.

As of 2015, there were 29 megacities with populations over 10 million, and by 2030, it is expected that there will be an additional 12, with 10 in Africa and Asia. Polycentric metropolitan regions, which are made up of several connected large urban areas, have gained prominence in recent decades, creating new challenges in transportation planning. For sustainable transport, technological innovation is essential (United Nations, 2016) and effective, well thought-out stormwater design is crucial for safety and infrastructure longevity. This is where Building Information Modelling (BIM) plays a vital role in better tackling these new challenges and design complexities. With the progression in technology, BIM has been implemented, adopted, and mandated by many countries across the world, seen as an intelligent, innovative necessity for enhanced civil infrastructure design, construction, and maintenance, helping us adapt to our changing world. This paper will be showcasing the application of BIM Technologies for intelligent, effective stormwater design. BIM technologies afford designers to incorporate and review designs as a whole, ensuring that the road design complements the stormwater design, as well as a range of other benefits and automated advantages such as the modelling of the stormwater network in 3D, checking of pipe flow directions, the incorporation and of popularly used local South African pipe catalogues, regrading of pipe networks as per cover and slope requirements, executing watershed analysis and catchment generation, as well as analytic and quantification capabilities in line with the South African Bureau of Standards (SABS) and the South African National Roads Agency Limited (SANRAL) drainage manual.

With BIM technologies, municipal engineers, civil engineers, consultants, and other design professionals can design and analyse stormwater networks in an intelligent and futuristic manner, promoting digital transformation and sustainable design, construction, and civil infrastructure delivery in South Africa and abroad.

INTRODUCTION

The objective of road stormwater design is to effectively discard surface runoff in a quick and efficient manner, protecting roads from deterioration, contributing to infrastructure longevity and commuter safety. Municipalities/municipal engineers are responsible for efficient road stormwater networks, forming a core function of the respective technical department. Optimally sizing, analysing, and constructing stormwater networks constantly pose a challenge to municipal engineering professionals, resulting in cases where stormwater networks being unrealistically oversized or undersized, impacting economy and functionality.

Intelligence, insight, and foresight are crucial in achieving an effectively designed stormwater network, with technology playing a pivotal role in this infrastructure requirement. BIM Technology, workflows & processes coupled with engineering knowledge enable the municipal engineering professional to provide infrastructure that is compliant, suitable, economical, sustainable, and innovative. This paper provides a high-level overview of BIM technologies that are nationally and internationally utilised, combining BIM technologies developed here in South Africa and abroad, with this paper elaborating on common tasks associated to road stormwater design such as derivations of catchments/watersheds and flow paths, as well as network modelling, analysis, regrading, resizing and quantification.

DERIVATION OF CATCHMENTS & FLOW PATHS

Stormwater networks are governed by the expected/calculated runoff, informing the layout and positioning of the pipe network and associated structures. A critical component in this process is the derivation of catchments and flow paths, which has a direct effect on the analysis and sizing of the stormwater network. This task is typically executed in industry by using Google Earth, in which the designer will plot out the extent of each catchment area that is contributing towards surface runoff affecting a road/road network. The plotting of catchment areas is based on the designer`s interpretation relative to the terrain characteristics, resulting in area values derived from plotted catchments/polygons. A flow path is then drawn by the designer anticipating the longest water path to the point of collection. The length and slope of this water path is recorded, with all required data usually inputted into an excel sheet or analytical engine.

There are a few problems with the above methodology:

- The data is static, meaning when changes occur, data needs to be manually updated or recorded again.
- The catchments & flow paths drawn are subjective to the interpretation of the designer.
- The catchments & flow paths need to be redrawn in a CAD platform, creating rework due to a data silo effect.

BIM technologies overcome all the above challenges and provide added benefits such as enhanced data collaboration, analysis, computation, and 3D visualisation. A preliminary surface can be accessed using geospatial engines, resulting in an intelligent terrain surface from which elevation data can be sampled and referenced off. When the accurate, latest survey data is received from the surveyor, the preliminary surface can be replaced and be set as the reference terrain, and all referenced values updated instantly, an advantage afforded

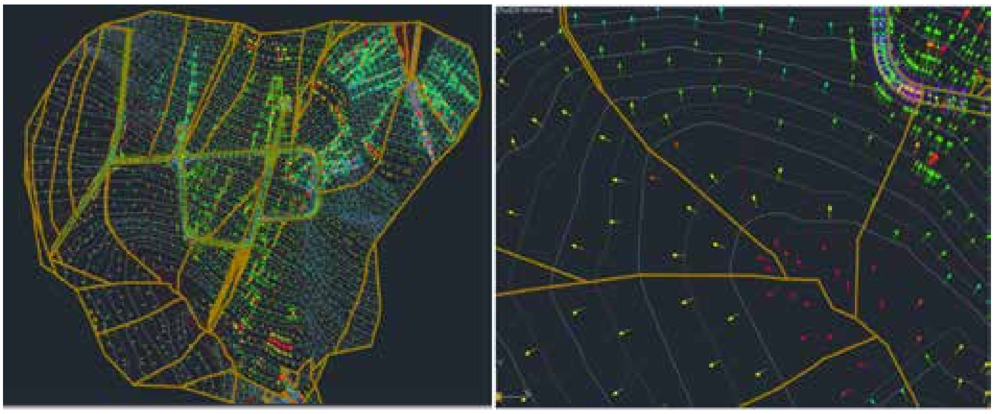

FIGURE 1: *Watershed Analysis Derived using BIM Technologies*

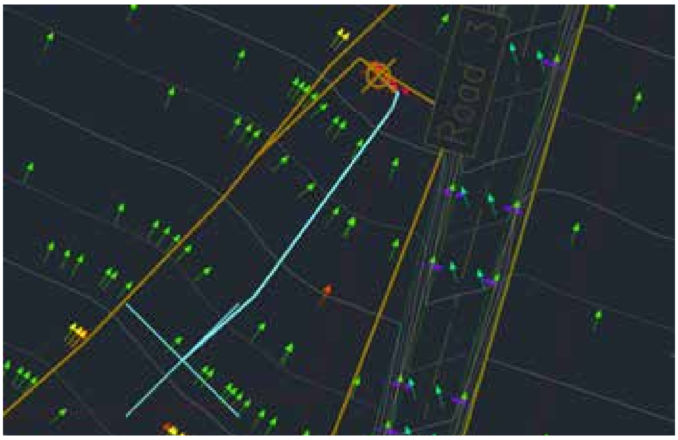

FIGURE 2: *Flow Path Derived using Water Drop Function using BIM Technologies*

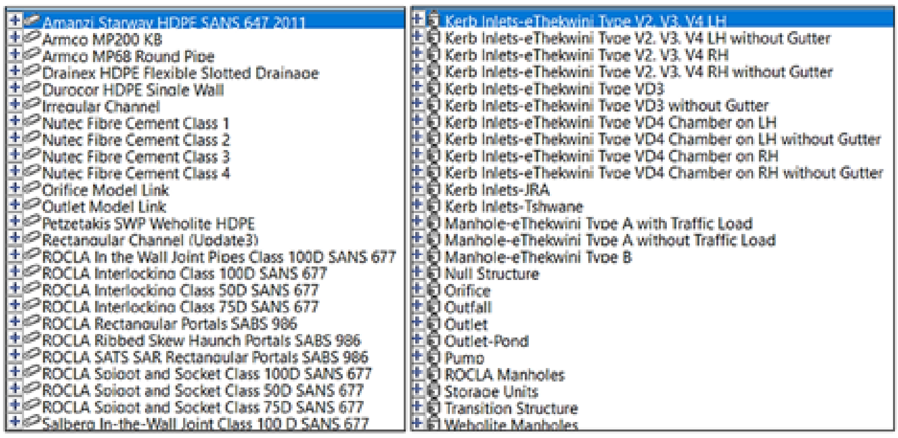

FIGURE 3: *Example of Available South African Pipe & Structure Catalogues*

by using dynamic, BIM technologies. With the terrain data available, a watershed and water drop analysis can be executed within the design CAD & analysis environment.

This results in a computational output, which is not purely subjective to the designer, providing an automated and analytical output, with the watersheds derived for a site depicted in Figure 1.

With the catchments computed, the designer can then identify the tributary areas and generate flow paths to inlets and/or low points using the water drop function, which computes the flow path of water from the point of selection as portrayed below, with the cyan X symbol signifying start of flow path.

MODELLING OF STORMWATER NETWORK

With the catchments and flow paths easy to derive in a dynamic, BIM technology environment, the pipe network can be designed and modelled accordingly. With the localisation advantage provided by locally developed software, commonly used pipe catalogues and structures in South Africa can be applied, allowing for accurate quantification.

The stormwater network can be modelled directly or generated from a polyline, with the option to swap pipes and/or structures, as well as check flow direction and specifying an outfall location by selection or by lowest elevation. Thereafter, long sections can be generated per branch and edited accordingly.

REGRADING OF THE STORMWATER NETWORK

When designing a pipe network, municipal engineering professionals need to be cognisant of design criteria such as pipe slopes and covers. Editing of pipe positioning can cause slope and cover values to be non-compliant, being difficult to verify manually. With the dynamic and analytical environment provided by BIM technologies, the designer can regrade a branch or entire network, ensuring that the slopes and covers are within the desired values. This automation affords the designer comfort, ensuring that all pipes are gravitating/flowing towards the correct direction, at the desired slope and cover ranges. Multiple pipes can also be selected and graded in either direction, ensuring that the pipes maintain a set slope.

Without the above automation and BIM intelligence, municipal engineering professionals are required to interpolate values manually per pipe, manually gauging pipe cover and elevation values which is monotonous and cumbersome, with the likelihood to miss something. These oversights are typically realised during the construction phase, resulting in revisions and alternative solutions that were not intended, planned for, or being reactive rather than practical, leading to increase in costs and delivery time. With the pipe network generated, the municipal engineering professional can now focus on the analytical nature of the stormwater network.

STORMWATER ANALYSIS

When designing a stormwater network, the network needs to consist of pipes and structures that are of optimal size to function efficiently. The sizing of the network is directly related to the expected surface runoff, i.e., the input analysis. With the combination of local and internationally developed software, the modelling and analysis can be achieved in the same interface, without the need to export/import across different software.

The runoff calculation methods available are that of Rational & EPA SWMM, with the option to specify analysis using steady flow, kinematic, or dynamic wave. With the Rational Method, the time of concentration (ToC) can be calculated using either Kirpich or Kerby formulae, with related analysis values derived from the SANRAL Drainage Manual and Intensity-Duration-Frequency (IDF) curves as per THE CIVIL ENGINEER in South

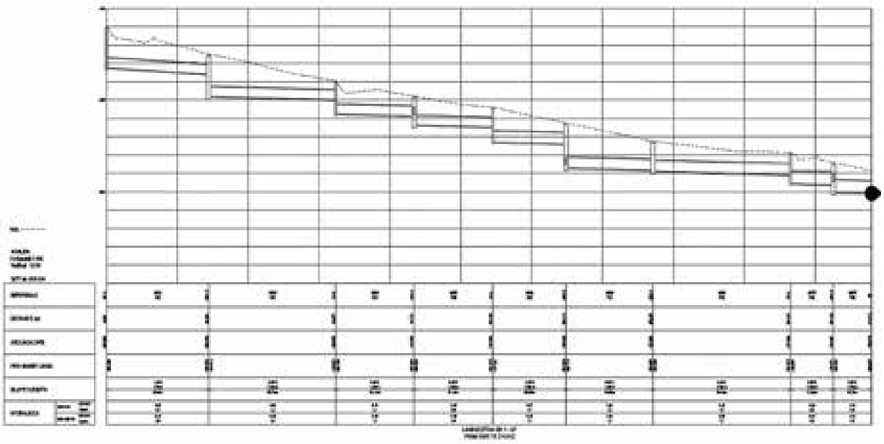

FIGURE 4: *A Pipe Long Section Generated using BIM Technologies*

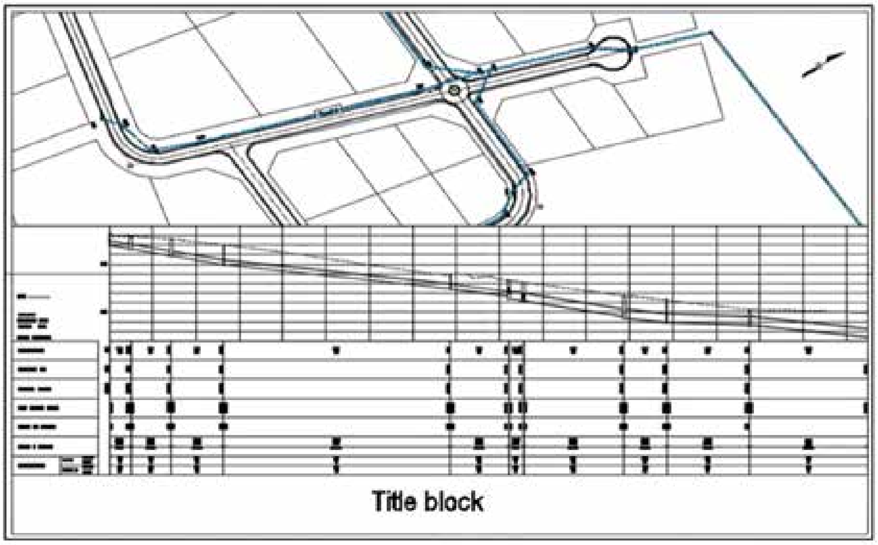

FIGURE 5: *Plan & Profile View of a Stormwater Network Generated using BIM Technologies*

	Inlet Structure	Length ()	Outlet Structure	Maximum / Full Flow	Maximum / Full Depth	Design Velocity (m/s)	Design Flow (m³/s)	Capacity Velocity at 0.8D (m/s)	Capacity Flow at 0.8D (m³/s)
1	KI1.1	28.695	MH1.1	0.130	0.250	1.530	0.061	2.496	0.444
2	MH2.2	24.529	MH2.3	1.000	1.000	1.720	0.405	1.721	0.397
3	MH2.3	38.793	KI2.3	1.000	0.820	1.720	0.405	1.721	0.397
4	MH2.1	22.263	KI2.2	0.890	[illegible]	[illegible]	[illegible]	[illegible]	0.261
5	KI2.1	28.837	MH2.1	0.220	[illegible]	[illegible]	[illegible]	[illegible]	0.444

The proportional flow depth is more than 80%

FIGURE 6: *Violation of Proportional Flow Depth Flagged*

FIGURE 7: *Analytical Values Available to Municipal Engineering Professionals*

Africa – March 1979. With regards to the EPA SWMM Method, the average catchment slope can be either specified or computed based on the start-end relative to the terrain, with equivalent width and rain gage also being able to be derived accordingly. This paper will provide a very high-level overview focusing on the Rational Method.

With the hydrology method set to Rational, the catchments and flow paths can then be selected individually or derived automatically. With the catchments, flow paths, runoff coefficients and inlet structures now specified, values such as flow path length, average slope, ToC, rainfall intensity, and runoff are computed per catchment. The Manning`s Roughness coefficient can also be set for conduits as dictated, including design velocity and maximum flow depth. Upon running an analysis of the network, the tabular information will flag items that are non-compliant as per the design criteria set. This provides an easier method to the municipal engineering professional to check the suitability of their design against the required specifications.

With this constant check of design versus specifications, the municipal design professional can analyse the stormwater network under various design inputs and return periods to arrive at a best suited solution, with options available on the top ribbon for ease of use as depicted in Figure 7.

With all these options available, the municipal engineering professional can now make an informed decision using intelligent, dynamic and intuitive BIM technologies to arrive at the optimal solution promoting economical and sustainable civil infrastructure delivery.

From a construction perspective, information such as setting out data, positioning, etc can be exported to a report or tabulated and included with the construction drawings, with the construction drawings typically following the format of plan and profile, with the plan view of the pipe network displayed above the long section of the respective pipe branch. With the adoption of cloud technologies and remote connectivity accelerated due to the COVID pandemic, the model of the stormwater network and associated layouts can be shared using a common data environment (CDE), enabling all involved to be connected in an environment catered to professionals in the architecture, engineering & construction (AEC) industry. The benefits of BIM and a CDE are numerous, such as the streamlined communication between design and construction teams, ensuring that issues raised on site are immediately communicated to the consultant, resulting in less delay time and problem resolution, all from a mobile device. Project tracking, reports, revisions, approvals, claim certificates, site logs, etc can all be executed and housed in this CDE, promoting faster service delivery and project completion.

Excavation Depth Increments (m) 1.0 Calculate Export BOM

Excavation Parameters
Excavation Volume (m³)
Excavation Volume Summary (m³)
Excavation Length (m)
Excavation Length Summary (m)
Pipes and Structures

	Pipe name	Part Size	Reference Surface	Bedding Class	Side Allowance (mm)	Message	Total Excavation	Bedding Cradle	Compacted Selected Fill Blanket	Refill	0.00-1.00m	1.00
6	P1.1	600mm Class 75D	Final Surface	Class A	300.000	<None>	18.715	4.094	8.231	6.391	14.049	
7	P1.2	600mm Class 75D	Final Surface	Class A	300.000	<None>	14.514	2.873	5.777	5.864	9.848	
8	P1.3	600mm Class 75D	Final Surface	Class A	300.000	<None>	33.557	3.299	6.632	23.626	11.299	
5	P1.4	600mm Class 75D	Final Surface	Class A	300.000	<None>	489.283	47.700	95.907	345.675	159.801	
4	P1.5	600mm Class 75D	Final Surface	Class A	300.000	<None>	77.744	10.556	21.224	45.964	35.198	
2	P1.6	600mm Class 75D	Final Surface	Class A	300.000	<None>	151.516	20.004	40.221	91.291	62.941	
3	P1.7	600mm Class 75D	Final Surface	Class A	300.000	<None>	43.624	6.898	13.869	22.857	23.689	
19	P1.8	600mm Class 75D	Final Surface	Class B	300.000	<None>	72.300	15.993	21.313	34.994	42.466	

FIGURE 8: *Excavation Quantities Calculated as per SABS 1200*

	Part Size	Total Excavation	Bedding Cradle	Compacted Selected Fill Blanket	Refill	0.00-1.00m	1.00-2.00m	2.00-3.00m	3.00-4.00m	4.00-5.00m
1	600mm Class 75D	2248.790	294.570	534.190	1420.029	930.281	846.041	371.703	71.938	5.987
Total		2248.790	294.570	534.190	1420.029	930.281	846.041	371.703	71.938	5.987

	Minimum Diameter (mm)	Maximum Diameter (mm)	Side Clearance (mm)
	0	125	300
	125	700	300
	700	1000	400
	1000	2000	500
	2000	10000	600

Structures

Structure Count Summary

Type	Quantity
Inlet	9
Manhole	14
Outfall	1

Pipes

Type	Length (m)
600mm Class 75D	727.231m
Total:	727.231m

FIGURE 9: *Calculated Pipe Network Quantities*

STRUCTURE LIST-STORMWATER

STRUCTURE NAME	Y	X	RIM ELEVATION	SUMP ELEVATION SUMP DEPTH	INVERT ELEVATION	MATERIAL
KI1.1	26 068.156	2 842 358.084	1473.019	1471.870 1.148	P1.1-INV OUT 1471.870	Concrete
KI1.2	26 032.753	2 842 221.829	1468.522	1467.530 0.992	P1.4-INV IN 1467.580 P1.5-INV OUT 1467.530	Concrete Concrete
MH1.1	26 060.501	2 842 350.483	1472.877	1471.650 1.227	P1.1-INV IN 1471.700 P1.2-INV OUT 1471.650	Concrete Concrete
MH1.2	26 073.129	2 842 348.695	1472.754	1471.449 1.305	P1.2-INV IN 1471.499 P1.3-INV OUT 1471.449	Concrete Concrete
MH1.3	26 066.464	2 842 343.096	1472.548	1468.327 4.221	P1.3-INV IN 1468.377 P1.4-INV OUT 1468.327	Concrete Concrete
MH1.4	26 024.576	2 842 195.202	1468.533	1465.935 2.598	P1.5-INV IN 1465.985 P60-INV IN 1465.985 P72-INV IN 1465.985 P1.6-INV OUT 1465.935	Concrete Concrete Concrete Concrete

PIPE LIST-STORMWATER

PIPE NAME	START INVERT LEVEL	END INVERT LEVEL	3D LENGTH TO INSIDE EDGES	SLOPE	DIAMETER AND CLASS
P1.1	1471.870	1471.700	10.026	1.579%	600mm Class 75D
P1.2	1471.650	1471.499	6.597	1.989%	600mm Class 75D
P1.3	1471.449	1468.377	8.417	35.301%	600mm Class 75D
P1.4	1468.327	1467.580	125.222	0.593%	600mm Class 75D
P1.5	1467.530	1465.985	27.285	5.547%	600mm Class 75D
P1.6	1465.935	1465.342	51.796	1.122%	600mm Class 75D
P1.7	1465.292	1464.477	17.495	4.478%	600mm Class 75D
P1.8	1464.427	1464.264	32.164	0.500%	600mm Class 75D

FIGURE 10: *Tabulated Pipe Network Quantities*

QUANTIFICATION OF STORMWATER NETWORK

Now that the municipal engineering professional is satisfied with the stormwater network design and all design criteria are met, quantification of the network is required to determine construction costs. With the power of BIM 3D modelling and South African Standards, these quantities can be derived, with the excavations calculated as per SABS 1200 specifications, with sample outputs portrayed in Figure 8, 9 and 10.

RECOMMENDATIONS & CONCLUSION

BIM technologies, workflows and processes combined with engineering technicality form the perfect duo to achieve sustainable, economical and design compliant infrastructure. With automation, computational and analytical capabilities, it affords the municipal engineering professional to design infrastructure that is built to last. At a municipal level, the adoption of BIM will result in insightful design, economical construction, and enhanced service delivery, and should it be standardised, usher civil consultants to contribute towards resilient infrastructure. In an era of daily technological advancement, and with the rapid acceleration in urbanisation and population, technology is imperative to keep up with service delivery, engineering a world today that will stand the test of tomorrow.

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