WHAT'S IN A VIEW?

Analysing View Quality Using 3D Isovist Ray Tracing To Inform Decision Making In A Multi-Story Residential Development.

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Abstract. In the architectural design of multi-story residential developments (MSRD), internal spatial organisation, solar access and thermal performance are factors that can heavily influence the placement of glazing and openings in an external facade. View quality from within apartments is more specifically significant to occupants and an apartment's market value, but is often described in subjective terms and is less easy to communicate in quantitative values. For these reasons view quality is less likely to be addressed as a parameter in early stage design that can be explored in relation to other more readily parametrised environmental phenomena. Adopting an Action Research methodology, this research collaborates with Crone Architects to analyse an MSRD in Sydney. Adapting a set of criteria developed by Li and Will (1997) to quantify and measure view quality this research will use the Decoding Spaces 3D Isovist Tool for Grasshopper. The outcome of this research project is a tool that can analyse, visualise and determine what percentage of a MSRD's context occupies the external view of a room. Extending this research further could be achieved through integration of Multi-objective optimisation. Exploring image recognition and machine learning algorithms, or sociological studies to determine an average approximation of view quality.

Keywords. 3D Isovist, Analysis, Multi-Story Residential Development, Ray Tracing, View Quality.

1. Introduction: (Research context and motivations)

Developing a project in the built environment is a difficult task in itself. When trying to quantify and metricise different aspects of a building that are subjective in terms of a user's perspective then the difficulty is multiplied. In the development of Multi-Story Residential Buildings (MSRD) designers spend inordinate amounts of time trying to optimise and perfect spatial layout, solar access, time schedules and other parametrised objectives. Rarely views are considered other than general orientation towards a point of interest or landscape feature. Originally this research set out to construct a multi-objective optimisation (MOO) workflow that would analyse the quality of a view from a room in an MSRD and optimise the layout to improve view and other objectives of a design process. With the limitation of time this research pivots its development to a tool that can analyse and quantify the quality of a view. Collaborating with Crone Architects an action research methodology is adopted. Using a case study of an MSRD in Sydney to analyse and evaluate view quality. Working with Rhino/Grasshopper3D (RGH), the Decoding Spaces Toolbox plugin 3D Isovist will analyse the view using ray tracing. This research will follow and adopt previous work from Lonergan and Hedley (2016) and, Li and Will (1997). The tool will analyse a set of criteria, consisting of: Ground, Parks, Water, Buildings, Infrastructure (roads), Sky and View Extent. These criteria will help quantify the quality of a view, showing the percentage of how much each element occupies the view. The view will be analysed from the centre point of rooms in an MSRD, creating an isovist volume. The aims of this research were to develop a tool that could be used in the early design development of and MSRD. While not wholly successful, this research shows that application of a 3D Isovist for view quality analysis can be achieved. View quality is an important metric in a buildings design, the absence or neglect of it severely affects the outcome of a successful design.

2. Research Aims

The original aim of this research was to develop a tool to analyse and quantify the quality of a view in a MSRD and optimise the layout in line with NSW State Regulation SEPP65 Apartment Design Guide (ADG) to provide better view quality. With the limitation of time and computational processes the original aim of this research has been pivoted towards: Developing a tool that can analyse and quantify the quality of a view from a room in a MSRD. It looks to develop a workflow that can take an area where

a MSRD is being developed, import context geometry, generate a tower, divide floors into rooms, generate viewpoints, analyse those viewpoints, collate the data and visualise the data.

3. Research Question(s)

In accordance with the shifted research aims the research question is:

How can view quality be determined and quantified using computational design techniques and tools?

Broken down into two sub questions:
1. *To what extent can 3D Isovist ray tracing be adapted to multiple viewpoints?*
2. *How will the tool be evaluated as working properly?*

4. Methodology

Action research (AR) is a methodological approach of "learning by doing" (O'Brien, 1998), it is problem solving using real issues and problems in a limited time frame. The integration of Design research (DR) is used to bridge the theoretical knowledge gained with AR. Using the "…heuristic optimisation workflow" (Ashour and Kolarevic, 2015), exploration and, trial and error, "designers can explore and generate creative solutions, making the initial design intention possible" (Moreno-De-Luca and Carrillo, 2013). O'Brien (1998) states "Action research follows a cycle of planning, acting, observing and reflecting". Compared to other methods of research AR builds upon previous research as a method of introducing change into their own research, rather than peer reviewed replication. Incorporating human ecology AR is used to modify and affect the environment it is based. Whereas traditional human ecologists research is mainly descriptive and analytical in studying the interactions of the environment with subjects (Findeli, 2010).

This research uses AR with a case study of a MSRD in Sydney in collaboration with an industry partner: Crone Architects. This research intends to analyse the environment of visual aspects and qualities of residential living in MSRD's. Adapting a method of qualifying and quantifying views from Li and Will (1997). The outcome of this research is a tool that can analyse and evaluate a room's view.

An abstract evaluation of view quality set out by the industry partner will be the basis by which the research will quantify the views achieved with ray tracing simulation. A visual collection of data will be generated on what each view point from an apartment interacts with. Analysing these results with consultation of the industry partner. The cycle of ray tracing and

visualisation will be repeated, with the review of the results being compared to the desired outcome of the research objectives.
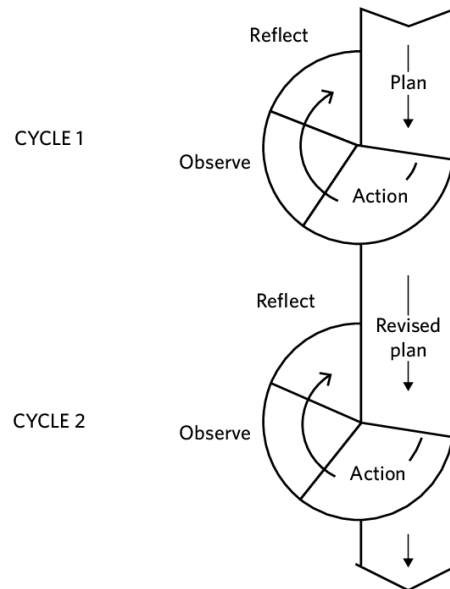

*Figure 1. O'Brien's simple action research model. (*from Kemmis, 1995)

5. Background Research/Literature review

5.1. 3D ISOVIST AND VISABILITY ANALYSIS

"There are many different forms of geometry, mobile actors, and observer-observed relations in the built urban environment." (Lonergan and Hedley, 2016). The research of Lonergan and Hedley (2016) is extensive and well researched in the field of Isovist development. Developing a set of criteria to define different sets and uses of Isovists (Figure 2). Quoting Benedikt (1979), Lonergan and Hedley (2016) define an isovist as "… the volume of space representing the visual field of an observer from a specified origin." For a majority of Isovist research it has typically used the panoptic omnidirectional visibility approach on a 2d plane. "Often it does not reflect real-world observers, each with varying needs and limitations (People; cameras; lookouts)." (Lonergan and Hedley, 2016). This research uses a non-dynamic isovist, defined as an immobile, fixed, non-focusing point.

Table 2. Proposed dynamic isovist classifications.

Is the isovist...	Moving?	Scanning?	Focusing?
Yes	Mobile	Scanning	Focusing
No	Immobile	Fixed	Non-focusing

Figure 2. Dynamic Isovist classification (Lonergan and Hedley, 2016).

This research sets the maximum distance that the isovist can see. This is similar to most research encountered "…select maximum distances for isovist limitation."

"…persistent issue with 3D isovist analyses is that most mainstream GIS platforms are not yet optimized for this type of analysis." (Lonergan and Hedley, 2016).

Lee et al. (2019) focused on urban design and layout, constructing a view analysis script using 3D isovist tools to measure visual features of the landscape. They highlighted urban view analysis tools such as Ecotect, Space Syntax and ArcGis and the inflexible nature of the programs to analyse dynamic modelling. "Because of this, 3D modelling software [Rhino/Grasshopper 3D (RGH)] was used to design the 3D isovist geometries in this research." (Lonergan and Hedley, 2016).

The first step within the process before analysis is generating context. This research aims to generate spatial context automatically, however Birge et al. (2016) and Hwang and Lee (2017) create their context as simple models in RGH "…leaving out intricate details such as decorations and textures." (Hwang and Lee, 2017). Birge et al. (2016) toolset focused on analysis using raytracing between neighbouring low-rise residential structures. Computing distance and penetration of rays into the interior spaces. The method used could be seen to be adaptable to this research's method. Similarly Hwang and Lee (2017) computed the analysis of privacy in public and private spaces along a simple path set out around the compound. Dividing the path and using ray tracing from points along the path at average eye level (1.6m) they calculated the quantity of privacy when viewing from the exterior. Although Hwang and Lee (2017) and Birge et al. (2016) aspects of analysis could have been better in quantifying the quality of a private space they show promising methodologies.

5.2. QUANTIFYING QUALITY OF VIEWS

Exploring current literature it seems that there is a limited scope of research addressing the issues of views within the parameters of a buildings design. Main research on views focus on privacy, with few research articles examining "quality" views in the context of their environment. Wageh and

Gadelhak (2017) note only a few studies consider view as one of the main objectives. "View is one major factor that leads to the satisfaction and comfort of the users inside the building enclosure." (Li and Will, 1997). Birge et al. (2016) states that "Social sustainability, due to its inherent unquantifiable nature, is often considered secondary to environmental and economic sustainability."

Hwang and Lee (2017) focused their case on the privacy within a traditional Korean castle. Quoting Irwin Altman (1975) "Privacy is a process of adjusting contact and approach distance with another person or a group" (Hwang and Lee, 2017). Their research was focused on analysis, trying to visualise privacy in a 3D simulation.

Qualifying the view quality, as the level of glazing interference Conti et al. (2015) used the analysis to generate the cost value of a view. They used these parameters to optimise the optimal solution between shading and view obstruction. Ashour and Kolarevic (2015) used a case study of the Bow Tower, Calgary, designing their toolset as a way to increase Floor Area Ratio (FAR) to increase profit. Their hypothesis "...that a larger range of solutions can be generated with the relaxation of objectives (i.e. fewer objectives) which ultimately will lead to better performing design solutions." Using the Ladybug (LB) plugin for RGH, they used a simple view plane to analyse views.

Li and Will (1997) were the earliest to utilise and optimise views spatially using a parametric software developed by themselves, called Interactive Optimisation Tools for Architects System (IOTA). This research, a case study of multi-story residential buildings in Hong Kong was promising showing, an intended method similar to this research's current method. Dividing a structure into 3m x 3m cubes, these would act as a basis for rooms. Qualifying views, Li and Will (1997) turned to studies on psychological aspects of views done by "Markus and Gray (1972)". Correlating views to five "fuzzy" sets, such as sea, vegetation, landscape, buildings, etc. Further research and development of this tool does not seem to extend past the 1997 article. The research of (Li and Will, 1997) seems the most substantial in terms of elements that can be adapted for this research. Adapting the elements of sea, vegetation, etc. align with aspects of the analysis this research and Crone are aiming for.

5.3. VISUALISATION

The visualisation of the results and presentation of information must be intuitive and readable by the end user of the tool. This aspect must be focused on when utilising the toolset for user interaction other than the tool designer. Bradner et al. (2014) states poorly designed user interfaces lead to designers having a difficult time understanding a design solution. The end

result of this research must take care in providing an optimal design solution that can be interpreted by the client with minimal confusion.

5.4. MULTI-OBJECTIVE OPTIMISATION

"…the intention of a building designer, through the process of creation, is to develop a creative, innovative, and optimum architectural object" (Moreno-De-Luca and Carrillo, 2013). MOO is the computational process used by designers to optimise multiple parameters of a design using conflicting objectives. The computation method of MOO is using a number of generative and evolutionary algorithms. Bradner et al. (2014) main take away was that the majority of uses of MOO and optimisation in industry happens at the start of design process. MOO used early in the design stage is intrinsic in the correct setup of parameters and objectives. The setup of a MOO workflow as the anecdote of a UNIX system programmer used by Tsigkari et al. (2013) can then be considered as such: write a program to do one thing, then write a program to work together.

The objective of this research in creating a view analysis tool can be seen as setting up a program to be incorporated into conflicting objectives; influencing the design of a MSRD in relation to other analysis. Automated spatial planning can achieve rapid generation of optimisations for a designer to make decisions in relation to a building in its context. Research in to the generation of layout in response to view analysis could follow the methodologies outlined by Sanguinsin (2019) for use in their layout generation toolset.

6. Case Study

Originally the aims for this research were to make a view quality analysis tool and a multi-objective optimisation workflow to better orient the rooms and floor plans towards a better view. The main component Crone wanted to test was whether it was feasible to develop one or two towers on the site, and what would perform better. The script was to incorporate parameters from the NSW SEPP65 Apartment Design Guide (ADG) and also include a privacy analysis element. Towards the end of the project the objectives of views and privacy were to be combined with M. Ooi's wind analysis script for MOO, to better design a tower that can respond to its contextual conditions.

The site of this case study is located at 175 Liverpool Street, Sydney. Situated at the southern end of Hyde Park. Currently there is a commercial tower occupying the space. Crone Architects have submitted a design proposal with the City of Sydney to demolish the commercial tower in place of a MSRD. The site is bordered on the east and west side by other

residential developments and on the southern side by medium rise commercial buildings.

6.1. WHAT'S IN A VIEW?

Early in the development it was discussed with Crone Architects what elements of the context surrounding the site were going to be analysed. Initially, it described as only assessing points of interest around Sydney: St Marys Cathedral; Harbour Bridge; Sydney Opera House; Hyde Park; Sydney University; Westfield tower; etc. In discussion with the research supervisor it was decided to also assess the extent of the view, how far can it see? After conducting more literature research and discussion with Crone, it was also decided to analyse elements that can detract from a view, such as roads.

6.2. IMPORTING GEOMETRY

The first task was to import a model of Sydney into RGH. Crone supplied a model but it only contained buildings on the western side of Hyde Park. The model was also made of very detailed meshes, making the file almost 1 GB in size. There was significant latency in trying to move around the scene with this file. The next method trialled was to import data from an open source mapping service, Open Street Maps (OSM) and Mapbox. First an OSM data file was downloaded, using the RGH plugin Elk. The OSM file gave the layouts of buildings, parks, roads, waterways, train lines and other infrastructure. A major issue was trying to find the height data to represent the buildings in 3D. Efforts using Mapbox to generate height data from a GeoJSON did not provide the correct results. In discussion with Crone it was suggested using CADMapper. CADMapper used the same geometry from Mapbox and generated a Rhino file of the geometry (Figure 3). CADMapper was a commercial solution, costing around $20 AUD for a 40km^2 model of Sydney. The model came with buildings, roads, parks, water and railways separated into different layers. The file was about 20 Mb in size and was relatively easy for the computer to handle. The next step of the process was decide how to analyse the context geometry.
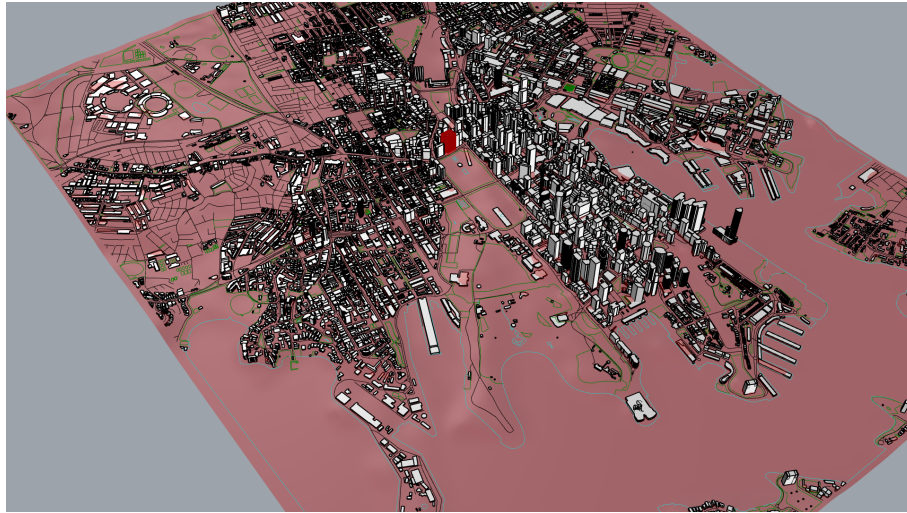
Figure 3. CADMapper File

6.3. INITIAL RAY TRACING TESTS

Tests were initially performed of different RGH plugins to determine which would best suit the needs of this research. The first tool tested was LB view cone and view analysis. The LB tool was found to be useful for testing 1 to 2 points of view, but the load on the computer was quite high and there was significant latency in changing settings. The next method was to use the ray tracing component from LB, to see if it can be adapted from solar reflection analysis. There was an issue here in that the rays would have to be set to a defined number of bounces and couldn't be culled after the impact with an object. After a number of tests it was determined LB was not suitable for this type of analysis.

6.4. 3D ISOVIST

In discussion with the research supervisor it was suggested to use the Decoding Spaces Toolbox (DST) 3D Isovist. Like LB plugin, DST 3D Isovist also utilises ray tracing as the main component. The 3D Isovist (Figure 4) takes a number of inputs to run the analysis. The first set of inputs are points from where the rays will project. A ground surface as a mesh. Obstacle surfaces as a mesh, these will be the buildings and other objects being analysed. View direction, this is a vector that tells the tool what direction the view is facing. View Range, how far will the rays will project. Horizontal and Vertical angle, to adjust angle of view. Horizontal and

Vertical precision, how many rays will be projected horizontally and vertically.

The outputs of the 3D Isovist are Ray Geometry (RG), a list of all the rays as vectors coming from the points. Length (Len) of rays as a number. Rays to Vantage Points (RtVP) as index of rays hitting nothing, hitting an object and hitting the ground. Object Visibility (OV) as an integer of how many rays hit a particular object in the view range.
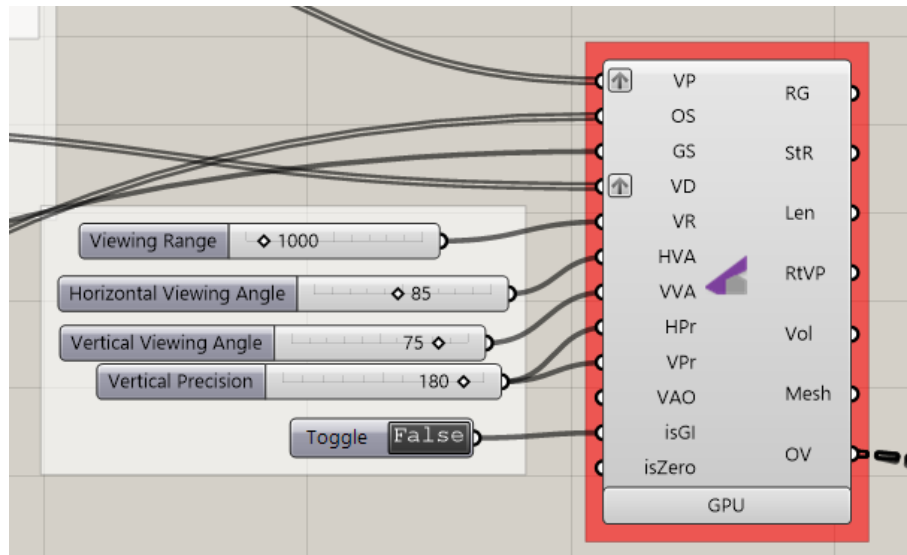

Figure 4. 3D Isovist.

6.5. MULTIPLE VIEWPOINTS

The next step in was setting up and testing the view analysis components for multiple viewpoints. A mock-up (Figure 5) of a MSRD towers north face was created and was divided in to 31 floors 3.1m high and rooms 3.75m x 4m. A mock up city was created with 50 randomly generated boxes between 20m and 50m wide and 20m to 100m in height. The centre point of the rooms were taken as the viewpoints to be tested. The angle of view for the horizontal was set at 85 Degrees and the vertical at 75 Degrees. The number of rays were set initially at 50 rays horizontally and vertically. View direction was set at the Y vector and length was set at 500m. The 3D Isovist ran for about 1-2 minutes.

Visualising the results with the vector display component for the rays, and cull list and gradient components for the buildings and rooms. The first

issue discovered was that rays were being projected from a single point. The solution to fix this issue was to graft all the points.
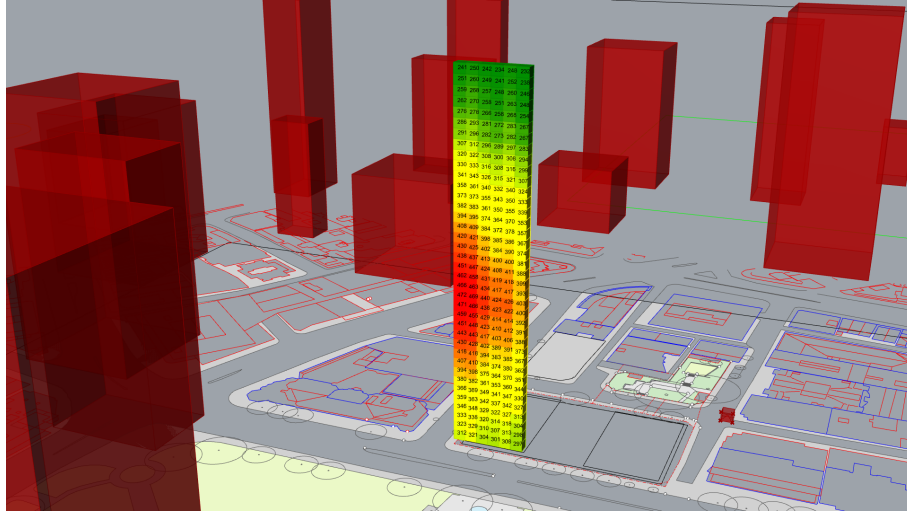

Figure 5. Tower mock up.

6.6. ANALYSING THE TOWER

Following the successful test of multiple viewpoints the next step in the process was creating a component that can produce viewpoints for rooms on all sides of the tower as well as corner rooms.

Crone provided a Revit model of a MSRD tower, but it was decided to make a simple mock-up of the tower in RGH so that it could be adapted for a multi-objective optimisation workflow.

A script was created to make a simple representation of the tower (Figure 7). Crone provided a set of parameters to develop the tower at 50m x 30m, a podium with 7 floors at 4m high. The residential part of the tower was set at 28 floors at 3.1m. This created a tower with a total height of approximately 115m. Rooms were to be approximately 3.75m wide and 4m deep. The centre point of the room at 1.55m would be the view point for the analysis. The script divided the perimeter of the floor into the rooms, and created a set of vectors from the points in the direction of the external view.

The viewpoints and the vectors were plugged in to the 3d Isovist and the analysis was run. The analysis ran for about 15mins.

Problems encountered were the rays were only calculating off one vector. With every ray pointing in the X direction. After a trial and error it

was discovered that the vector input also had to be grafted as well as the list of vectors duplicated to match the list of viewpoints. After this issue was solved the results looked promising, showing what boxes were obstructing the views for each room.
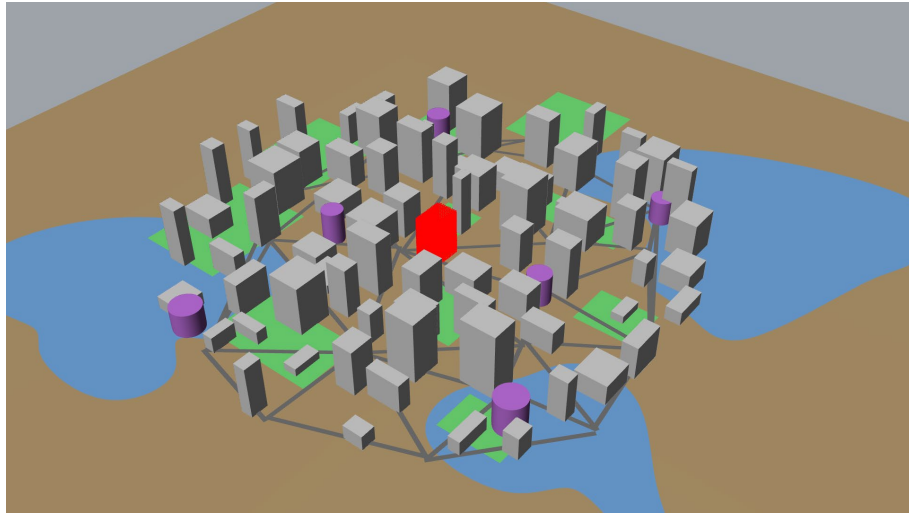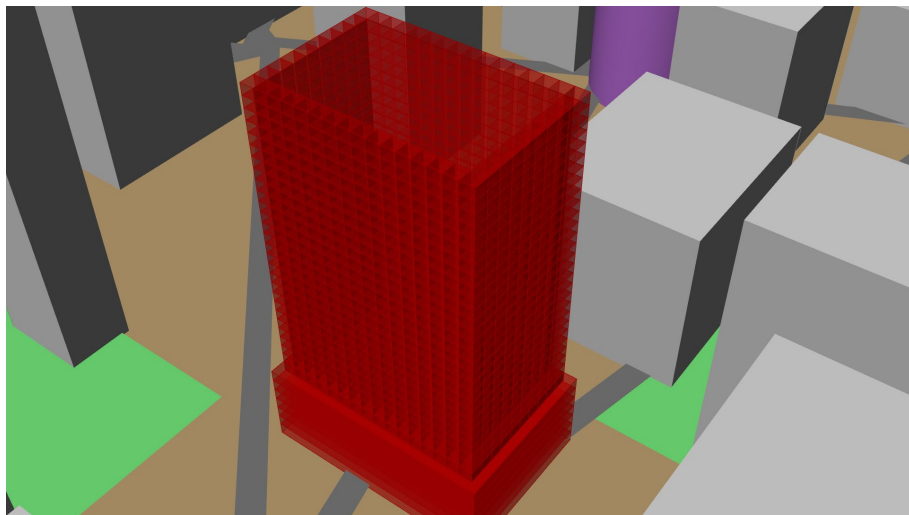

Figure 6. Test City

Figure 7. Tower

6.7. CONTEXT GEOMETRY

After the success of the test runs it was decided to run the analysis using the context geometry of the site. The CADMapper model was imported into

RGH and separated into their elements as meshes of: Ground, Parks, Water, Buildings, POI, and Roads.

Initially when the analysis was run the computer would freeze and it would not be known if Rhino had crashed or if it was running. After a number of abortions of the analysis process, the context geometry was culled to a small radius of 100m around the tower and run again. This seemed promising as the analysis only took around 15mins. The results also showed what the problem was with using the CADMapper geometry. The test geometry was only simple blocks, the mesh only constituted 6 Faces. Whereas with the CADMapper model some buildings could possess anywhere from 6 to 120 mesh faces. The construction of these meshes exponentially increased the amount of surfaces being analysed as well as the time it took to calculate.

This problem was discussed with Crone and it was decided to let the analysis run with full context geometry. The settings for test run were set up as: 85 degree horizontal and 75 vertical viewing angle, 180 Rays horizontally and vertically, and a 1000m view range. The analysis was set to run and left alone. When completed the analysis took 4.5hrs. Because of the amount of meshes in the scene and the number of rooms in the tower, the number of values for the RG and OV were at around 20 million values for each output. This was as also the same for the outputs that weren't being considered. Moving around the RGH interface became incredibly difficult with plugging in or enabling the preview of component taking 5 minutes for the computer process.

Trying to save the data to the GH file resulted in Rhino crashing and the loss of all the data for the 4.5hr analysis.

Rolling back to analysis of the test city geometry, this was used to test different storage methods. After some initial research TT Toolbox's Excel read and write component was used to save the data from the analysis into an Excel workbook. The Excel method showed promising results, being able to reduce latency of the GH interface significantly.

Running the analysis again with full geometry at another 4.5hrs computation time, the data was successfully written to an Excel workbook. The total size of the workbook came out to 90mb with 6 worksheets each holding around 1500 columns and 18,000 rows.

When reading the data the latency was again reintroduced, with it taking about 5 minutes each time a component was selected to unfreeze.

After this point it was decide with the remaining time left for the research to be completed that the analysis will have to be completed using the test geometry generated in GH.

7. Discussion (evaluation and significance)

The initial aims of this research were to produce a tool capable of MOO. Due to the complexity of view analysis alone the initial target of MOO was reconsidered and omitted and would potentially form a future stage of research.

This research has produced a tool to analyse the quality of a view from an apartment in a MSRD. The tool uses ray tracing to determine the interaction of contextual elements surrounding the external view from a room and compares it against the other rooms in the MSRD. The tool produces data in the form of vectors from the viewpoints; integers of which elements are being hit; and the amount a view is occupied by that element, be it a building or green space.

The tool is successful (Figure 8) in that it analyses and returns a value of the room's view being obstructed. However it is only able to achieve this using very simple context geometry generated in script. The main limiting factor to the delay in production of the tool was computation power available. For the analysis tool to be truly successful and use the geometry provided, a solution needs to be developed to handle the processing of the large amount of data produced by the 3D Isovist component.

Building upon the 3D Isovist tool and the research performed by Lonergan and Hedley (2016). This research uses the tool in a manner that it has not been intended to be used. Taking the 3D Isovist tool and using it for multiple vantage points along a building rather than a single vantage point in an urban layout testing blind spots at intersections. Creating an isovist analysis of a volume, rather than a single point or path.

Other view analysis tools are simple in their execution usually only testing one view point to test privacy or solar access. There is merit in using a 2d method as the amount of data produced for multiple viewpoints is quite large and difficult to process without significant lag.
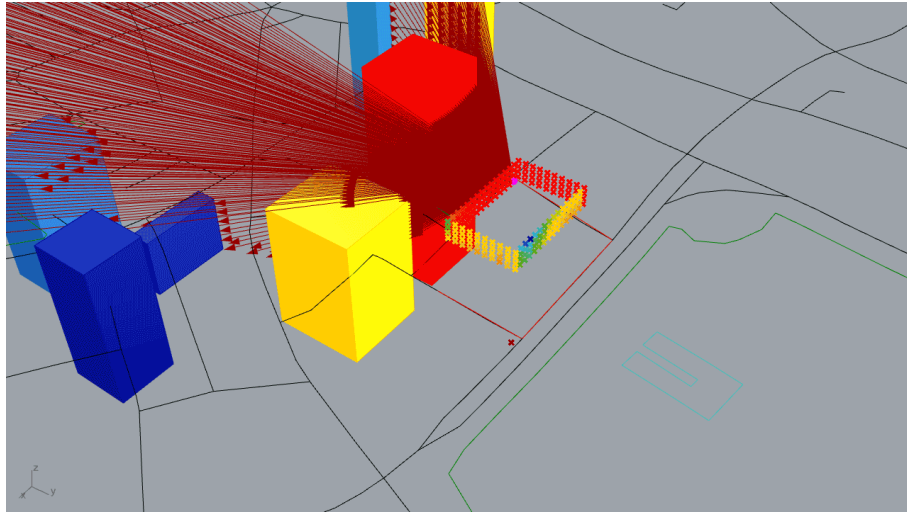
Figure 8. Ray Tracing

With further time and resources committed to the project this research would look to incorporate number of objectives. Incorporation of the building geometry provided by Crone. A method that includes testing against the visibility of the façade. Also the inclusion of an analysis of privacy, and how the views interact with surrounding buildings. The development of multi-objective optimisation to provide a designer with solutions to the problems presented by the analysis. Update DST 3D Isovist or develop a better ray tracing component to handle the task of multiple viewpoints. Write a python database script to better handle the storage and processing time of the ray tracing data.

Compare visual processing algorithms to ray tracing to determine which method of view analysis returns more accurate results. Moving the tool to an online application or integrating with GIS that can be used for initial design stages. Research image recognition and machine learning algorithms to that can identify pictures of environments on social media with higher numbers of user interactions to determine values of view quality. Or to take human ecologist workflow and Conduct a research survey of which views people prefer for an apartment.

8. Conclusion

The quality of a view provides significant contribution to developer profit and occupant comfort. The exclusion of addressing views in a quantifiable manor limits and hinders the role of a designer to provide intelligent solutions to existing problems.

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