The Biomimetic Solar City: Solar Derived Urban Form using a Forest-growth Inspired Methodology.

Craig Lee Martin[1] and Greg Keeffe[1]

[1]The Manchester School of Architecture, Manchester, United Kingdom

ABSTRACT: The Northern European solar city, with its low solar altitude is an oxymoron: buildings close together shade each other. This is particularly true in winter where low sun angles cast long shadows. European cities contain other problems; their early development has left remnants of medieval street plans that have no inherent solar orientation. In England in particular, it seems very unlikely that there will ever be any large-scale urban re-planning of cities on solar principles. In light of this, how will it be possible to develop the city so that each block gains maximum solar exposure, without unduly disadvantaging other blocks to do the same?

With initial reference to Ralph Knowles' 'Solar Envelope'[1] and 'Interstitium'[2], this paper creates and uses a mapping of city and forest, in order to develop new methodologies for growing a city using Sernander-type gap dynamics[3]. By recognizing the forest (and city) as an intensified, light stratified system, grown through a sequential process of 'succession' this study has identified a flexible sunlight and daylight strategy for the volumetric development of brownfield urban sites.

Keywords: Biomimetic, solar City, Northern European, Forest-Inspired.

1. INTRODUCTION - SYNERGY CRYSTAL

Manchester, England (53.7°N 2.1°W) was to become the world's first unplanned and chaotically arranged industrial city (Fig. 1). The city plan and the built forms that now dominate are essentially Victorian and Edwardian due to its transformation from medieval settlement to an industrial Cottonopolis during the nineteenth century. Indeed, the rate of change in the architectural, cultural, political, social, scientific, and medical fields was so great that Manchester would later be regarded as the world's first *Shock City*. Despite the introduction of a Model Series of Bylaws in the years that followed restricting building height for reasons of health and sanitation, there would be no specific solar influence in Manchester's planning. Composed of variously oriented gridirons, Manchester streets have acquired subtle changes in angle. Contained within this framework are blocks that vary in size and shape allowing for numerous routes across the city.

Despite massive redevelopment Manchester remains an unchanging gridded context, its low-rise form, latitude, climate, and organically compact urban grain continuing to conflict with the principles of passive solar design. The need to address overshadowing, inevitable for most of year, became the main argument of CAD generated 'Synergy Crystal'[4] form (Fig. 2), and the reason why Manchester continues to function as a solar city test site for current research.

Synergy Crystal research concluded that solar aperture in Northern Europe was an important form generator by using hourly solar data at three times

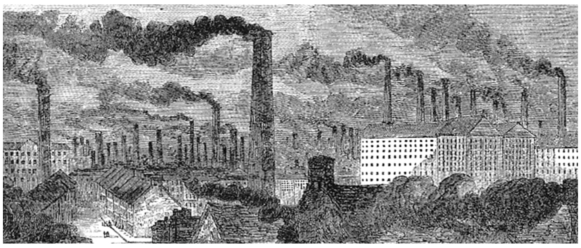


Figure 1: 'Manchester, Getting Up The Steam', Manchester's unprecedented urban growth illustrated in 'The Builder' (1853).

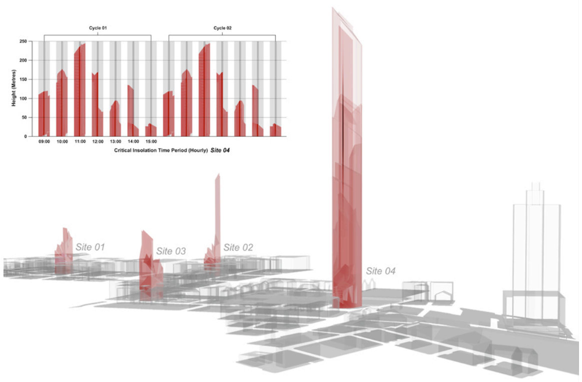


Figure 2: Based on the Solar Envelope by Ralph Knowles the Synergy Crystal aimed to produce a solar building form which was mutualistic with the existing city.

of the year (Summer solstice, Winter solstice, and Equinox) to develop a Perfect Passive Solar envelope (P.P.S.E.) that was not shaded by existing buildings. When the P.P.S.E. was intersected with the Knowles' Solar Envelope a 'Synergy Crystal' was created that had solar aperture, but did not shade existing buildings (Fig. 4a). The 'Synergy Crystal', guaranteeing solar access at specified times to neighbouring buildings, and simultaneously indicating, volumetrically, the energy conversion potential of the site itself for specific seasonal and diurnal time periods (Fig. 4b).

2. FOREST ANALOGY

2.1 Forest & City Metabolism

The analogy between the operational patterns of natural ecosystems and those belonging to sustainable development is an obvious but significant one to make: forest systems increasingly partition energy to maintenance and respiration rather then growth and production as they advance successionally toward maturity or climax; a phenomenon that Dumreicher et al., Redclift, and Yanarella make reference to in their critique of current unsustainable cities[6]. As stabilising mechanisms fail to operate, carrying capacity limits are exceeded once a city reaches climax. This leads to overproduction, a distinguishing and decisive factor that separates current cities from forest systems, and currently threatens the very existence of both synthetic and natural communities.

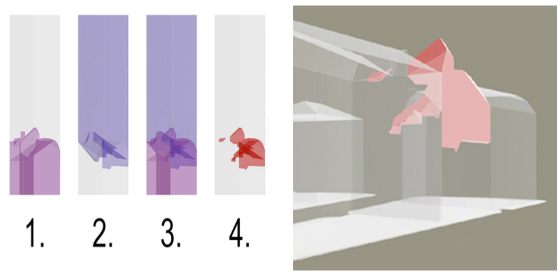
2.2 Light Stratified Superorganisms

There is an analogy between the forest and the solar city at the scale where species and building types interact. Recognizing the forest as an intensified, light stratified system (Fig. 5 & Fig. 6) grown through a sequential process of succession this study identified a flexible sunlight and daylight strategy for future Northern European brownfield compact city growth. The model advanced Synergy Crystal research by first interpreting then implementing natural forest gap algorithms or rules within an existing post-industrial Northern European landscape.

2.2 Forest Gap & Synergy Crystal Regeneration

Five analogies were identified between Synergy Crystal growth and forest gap regeneration:

1. Both Synergy Crystal (new shade-intolerant occupant of a brownfield gap) and replacement light gap species (single occupant of a forest opening) followed contextually growth rules as dictated by perimeter gap species.
2. Any tree species or Synergy Crystal capable of tolerating the new solar environment or ecological niche created by natural or synthetic disturbance will ultimately proceed to the next stage of succession.
3. Natural shade-intolerant species (termed Pioneer species by some authors) require a gap for regeneration. A Synergy Crystal, inherently shade-intolerant and a solar Pioneer, also requires a gap for regeneration.
4. In nature, intra-specific competition occurs when individuals from the same species compete against each other for limited resources detrimentally affecting population survival, fecundity, and resource levels. The objective of Synergy Crystal growth is to prevent intra-specific competition i.e. to prevent adverse overshadowing between existing and future sunlight demanding buildings or shade-intolerants.
5. The Synergy Crystal methodology actively exploits densification, a prerequisite for any synthetic solar community based on a forest model.



(a) (b)

Figure 4: Generation of Synergy Crystal urban derived growth. (a) Synergy Crystal generation in elevation, Newton Street, Manchester (1. Solar Envelope, 2. P.P.S.E, 3. Synthesis, 4. The Synergy Crystal). (b) Synergy Crystal in urban context.

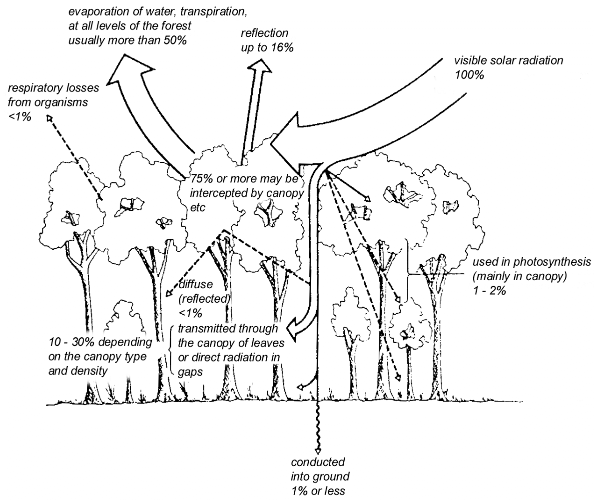


Figure 5: Modulating effect of the vegetation cover Packham et al.[7]. The forest is a multi-cultural, mutual ecology of differing needs co-existing. Within each layer of a stratified temperate or tropical forest, light is a limiting factor. Direct sunlight creates a shade environment, which through natural selection or more specifically coevolution, diffuse daylight derived species, namely shade-tolerants are able to survive.

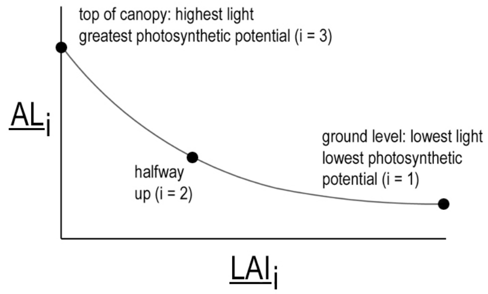
There were however, two significant differences between forest composition and the Synergy Crystal methodology, dissimilarities that would ultimately conflict with any successional analogy. These involved Sernander-type gap dynamics and Interspecific competition.

Synergy Crystal research stopped short of suggesting a community-scale solar model. Unlike the Solar Envelope, developed for the expansive gridiron of Los Angeles, the Synergy Crystal responded to urban pockets contained within an established, organically compact conurbation. If a biomimetic solar city based on forest algorithms were to succeed, it would have to respond to disturbances greater than the fall of a single building or tree. A solar city following forest Sernander-type patch dynamics initiated by multiple tree falls (Fig. 7) should then be capable of multiple self-growths. If not, any succession would tend towards a self-replacing climax of shade-tolerants.

Natural inter-specific competition occurs when two or more species populations adversely affect the growth and survival of each other in an effort to gain a limited resource i.e. direct sunlight. In nature specialisation between species ensures that inter-specific competition is muted as species retreat to their own particular habitat or ecological niche. The Synergy Crystal, an ecological niche inhabited by shade-intolerant species, visually identified specific periods of solar access. However, with no effort to minimise inter-specific competition, the methodology failed to consider an ecological niche capable of sustaining shade-tolerant species, and consequently could not utilize the same environmental mechanisms open to a natural forest system.

As the utilization of or tolerance of shade is critical within a light stratified forest system, the aim of the methodology was to embrace the physical compaction of cities and therefore the volumes of shade that will inevitably result. The objective being to grow a community of solar related forms that visually indicate regions where both shadow and sunlight occur at critical times of the day and season without compromising community solar access. Further, a solar resolution was sought that offered a compacted and contextually receptive alternative to expansive solar developments formulated by the oblique winter midday sun angle (Fig. 8).

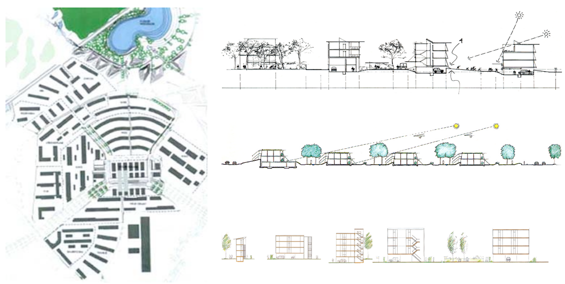
In the same way that a natural succession achieved a sustained and solar diverse community with an increasing level of growth prior to a climax, it would be argued that a synthetic community should also have the capacity to respond to varying light conditions brought on by urban intensification (In the UK the government has set a target for new projects to be built on previously developed "brownfield" of 60% to be achieved by 2008 [DEFRA UK GOV]). Current European solar housing prototypes typified by Linz-Pichling's SolarCity masterplan fail to complete this analogy with forest succession by only offering a solar monoculture (ie no shade tolerant types).



$$AL_i = e^{-LAI_i * k}$$

Figure 6: The Beers Law formula. By incorporating Leaf Area Index (LAI) into the Beers Law equation, light which decreases exponentially from the top of the canopy to ground level can be mathematically described [8].

Figure 7: Mature cedar-hemlock forest of British Columbia displaying Sernander-type patch dynamics. Larger fall of multiple trees creates multiple genomes competing for solar aperture in an iterative way.



(a) (b)

Figure 8: SolarCity, Linz-Pichling, Austria.
(a) Masterplan for 25,000 inhabitants containing 1317 solar energy dwellings with plans to increase this capacity to 6,000. (b) Low density due to oblique winter solar angles.

- 32 Hectare greenfield site.
- Context/history free.
- Presumes every building needs solar access.
- Monocultural.

3. GROWTH METHODOLOGY

3.1 Overview

Using a process of synthetic natural selection, city elements such as dwellings (shade-Intolerant species), offices and commercial premises (Shade-Tolerant species) are also able to interact daily and seasonally in a symbiotic way. In addition, a synthetic silvicultural process of seeding an urban grid enabled specific cities to be grown sequentially. Hence, terms that were previously the sole domain of forest ecology such as 'Pioneer' and 'Climax Phase', 'Shade-tolerant', and 'Shade-intolerant' are now brought into an anatomy of the solar city.

The climatic volumes produced by the methodology on sites in Manchester UK (53.7°N) were then compared with built examples from cities of similar latitudes (SolarCity, Linz), to show that the unorganized city can perform as well or better than the planned solar city.

3.2 Seed Grid & Growth rules

Solar growth began with the formulation of a contextualized urban seed grid, the random numbering of each seed grid subdivision continuing the speculative or heuristic nature of this study (Fig. 9). Through the implementation of various growth rules (some resource competitive) relating to solar and urban geometry, energy potential, and land-use, a community of solar-related volumes emerged that diurnally and seasonally apportioned periods of solar access to both existing and future urban form (Fig. 10).

In summary, the methodology for the growth of varying brownfield sites adhered to the following sequence:

1. Divide site into blocks.
2. Decide on order for seeding – this can be random or controlled.
3. Use solar azimuth and altitude for each hour on Equinox to create passive solar envelope which does not shade adversely.
4. Identify shade-tolerant layer beneath.
5. Boolean intersection of forms.
6. This gives shade-intolerant volume and a shade-tolerant volume.

3.3 Case study - Miller Street, Manchester City Centre

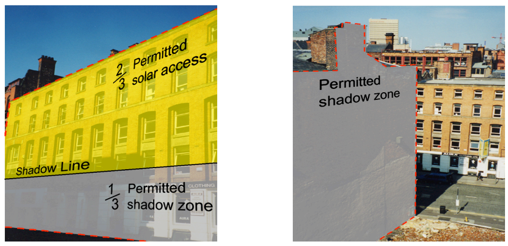
The following illustrations depict the sequential technique used during the growth of a dual shade-intolerant and shade-tolerant volume i.e. a volume partly overshadowed by either or both surrounding built context and any other generated solar forms grown previously in a succession (Fig. 11). In this case the grid had been 'silviculturally' seeded from north to south to allow optimal solar access to be allocated to all subdivisions. Subdivisions 1 to 5 have already been generated, subdivision 6 is next in the succession. All volumes are generated from Equinox solar angles for 12.00hrs.

This demonstration will also discuss how the composition of a resultant form grown earlier in the succession transform in accordance with new growth located immediately in-between itself and the Sun.

(a) 1745 (b) 1962

(c) 1745 - 2004 (d) Seed Grid Complete

Figure 9: Historical Seed Grid generation, Miller Street, Manchester. On completion individual subdivisions within the seed grid would be numbered randomly or otherwise to allow the grid to be grown sequentially.



(a) (b)

Figure 10: All growth rules related to periods of solar access, existing building/plot use, and present/future energy potential. For example walls of nearby buildings that function as window walls or that have window openings that are greater than 25% of the wall area may be partially shadowed by a generated volume, as long as no more than 33% was overshadowed during specified solar access hours (Fig. a), whereas walls of surrounding buildings that serve as firewalls or other vertical surfaces with limited window area may be totally overshadowed by Phenotypic form (Fig. b). Resultant volumes could not shadow above the roof parapet of any existing building during specified solar access hours, a move safeguarding the future potential of solar collectors installed on nearby roofs.

Under growth rule, the permitted amount of overshadowing on active façade (sub 4) must be evaluated.

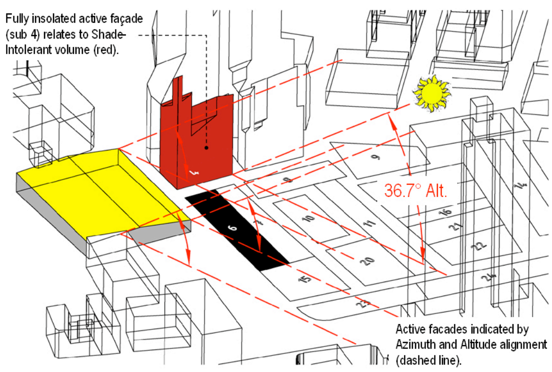
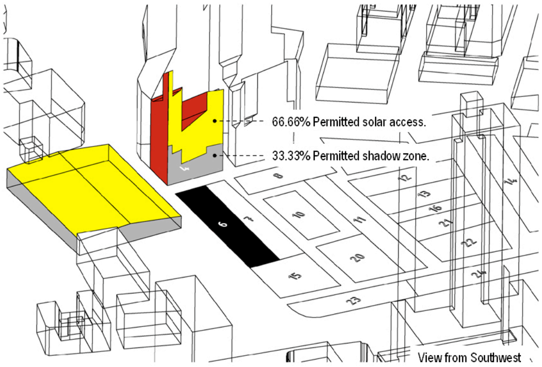


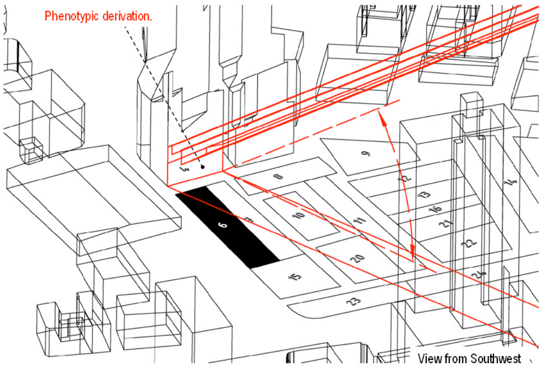
Figure 11: (a)

As facade under evaluation is fully insolated, rule permits a shadow cast from sub 6 equal to 33.33% of the total evaluated area. Note: This permitted shadow zone must be initiated from ground level.



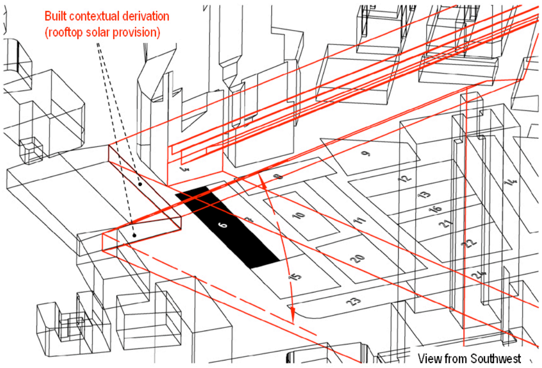
(b)

Solar Envelope wire frame. Envelope surfaces follow Azimuth and Altitude 'Path' that originated from the active façade of Phenotypic equivalent (sub 4).



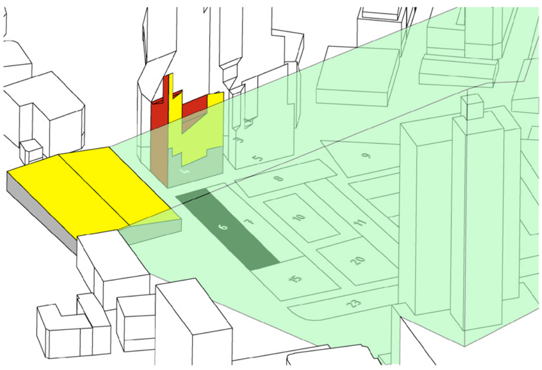
(c)

Solar Envelope wire frame. Envelope surfaces follow Azimuth and Altitude 'Path' that originated from the active façade of built context.



(d)

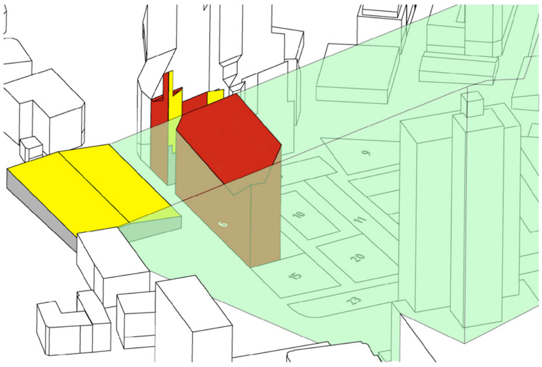
Solar Envelope shown to protect specified solar access of active facades (Phenotypic equivalent) and rooftops (built context).



(e)

Figure 11 (cont): (b) to (i)

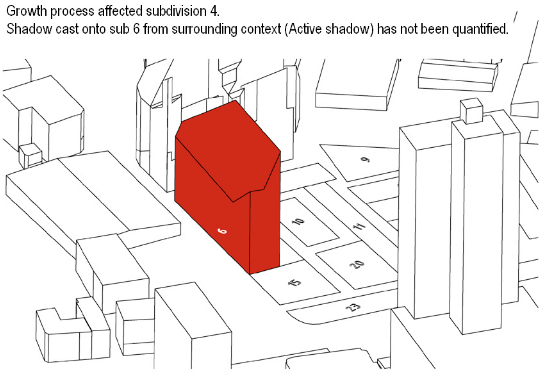
Identification of Solar Envelope volume contained within vertical extrusion of subdivision 6.



(f)

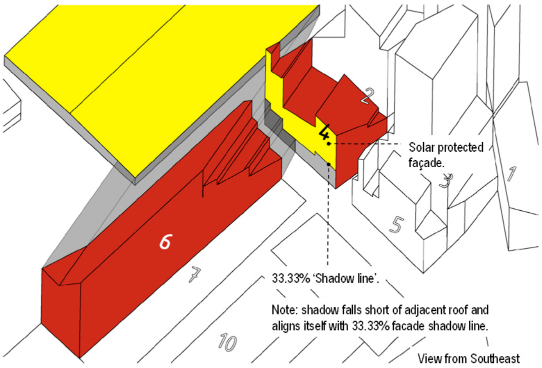
Generation of subdivision 6 volume not complete as:

- Growth process affected subdivision 4.
- Shadow cast onto sub 6 from surrounding context (Active shadow) has not been quantified.



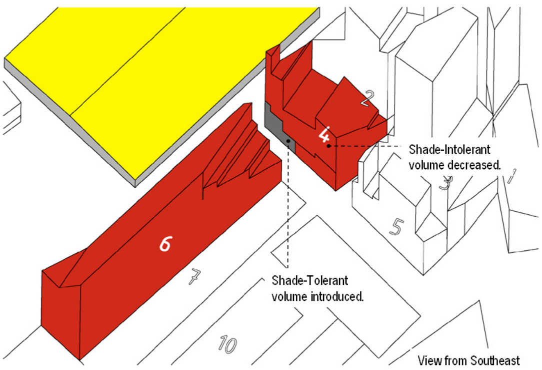
(g)

Shadow cast by subdivision 6 volume affects Phenotypic composition of subdivision 4.



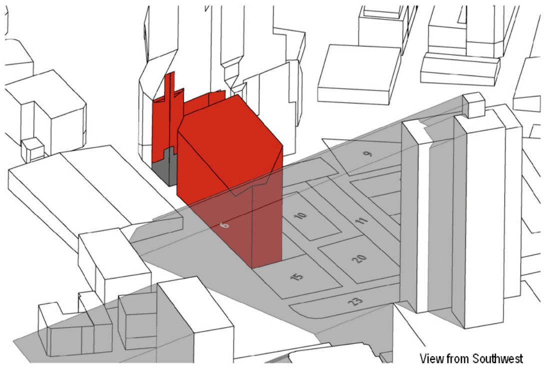
(h)

Shade-Tolerance volumetric composition of subdivision 4 has now been updated.



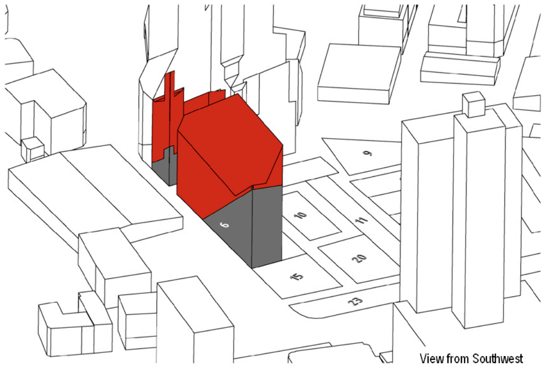
(i)

As shadow from surrounding built form encroaches boundaries of subdivision 6 (Active shadow), composition of Phenotypic volume must adapt accordingly.



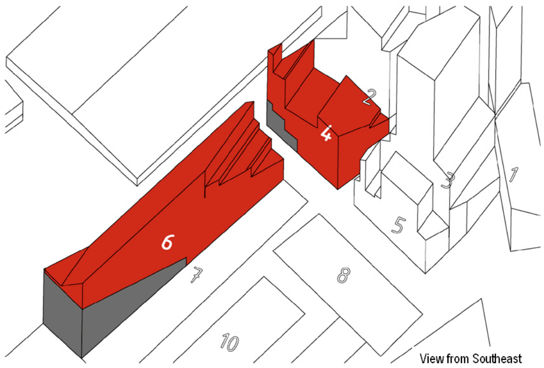
(j)

Active shadow introduces Shade-Tolerant Volume to Phenotypic volume of subdivision 6.



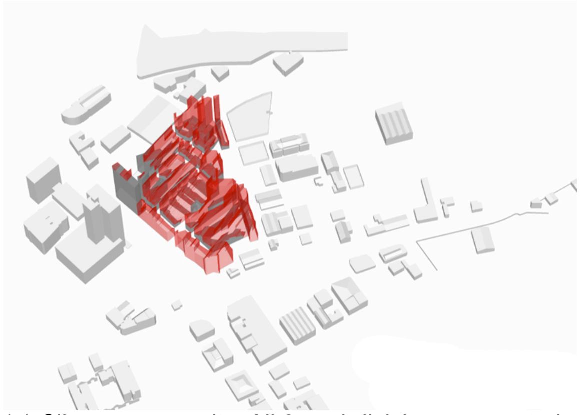
(k)

Generational growth process completed for subdivision 6.



(l)

(m)



(n) Climax community. All 25 subdivisions generated.

Figure 11 (cont): (j) to (n)

4. ENERGY COMPARISON

4.1 Calculation

Using Lambert's Cosine Law, solar irradiance at specified time periods can be determined by simply calculating the incident solar surface area for generated form throughout the developed succession and this can be compared with the built precedent.

4.2 Forest-Inspired Urban Form vs. Built Precedent

A comparative solar energy study involving Manchester's Smithfield Market seed grid (seeded north to south) and Linz-Pichling's SolarCity masterplan was conducted at hourly intervals during the Equinox.

The communities were paired during analysis because the Smithfield seed grid and all 5 residential sectors which form the SolarCity masterplan each contain a relatively high number of subdivisions, and have similarly sized footprints (Fig. 12 & Fig.13).

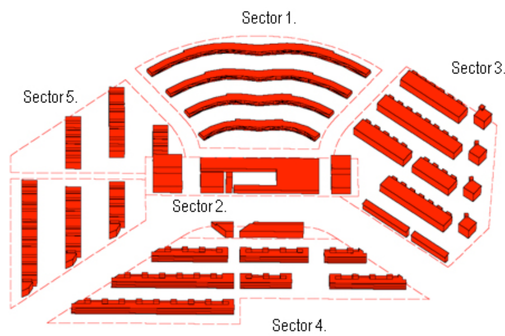


Figure 12: SolarCity, Linz-Pichling (Scheme presented 1995), Austria. Latitude: 48.19°N. Total Developable site area: 121131m^2 approx. Developable sector areas:
Sector 1 – 26440m^2
Sector 2 – 13076m^2
Sector 3 – 28135m^2
Sector 4 – 25747m^2
Sector 5 – 28135m^2

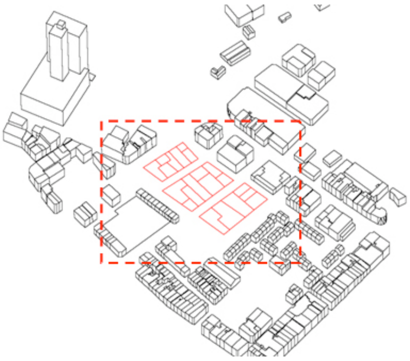


Figure 13: Site: Smithfield Market, Manchester City Centre. Latitude: 53.28°N. Total developable site area: 8832m^2 approx.

4.3 Results

Figure 14 compares the accumulative community irradiance pattern of successional urban growth at Manchester's Smithfield Market site with that of 5 residential sectors at Linz-Pichling's SolarCity masterplan. The graph includes two methods for solar growth on the Smithfield grid, SG 3 and SG 4, representing seeding from north to south and from south to north respectively.

Although 3 out of 5 sectors at SolarCity exceeded the total irradiance intercepted at Smithfield at the climax phase, suggesting that the solar performance of a forest-inspired community is below that expected from a solar city model, the developmental area of each site must be considered. As the smallest and largest sector site areas at SolarCity are ~13076m^2 (sector 2) and ~28135m^2 (sectors 3 & 5) respectively, and considering that the total developmental site area at Smithfield Market is only 8832m^2, then it may be assumed that the forest model performs favourably against SolarCity in terms of potential energy collection.

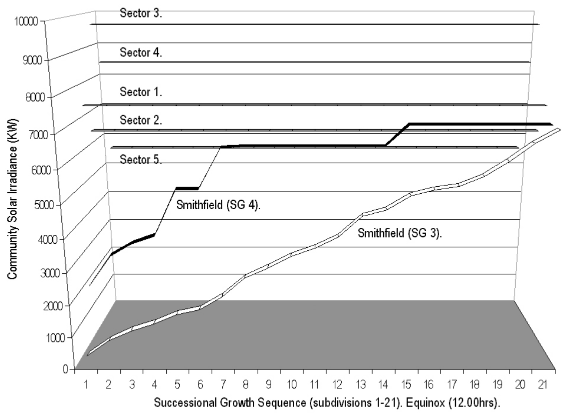


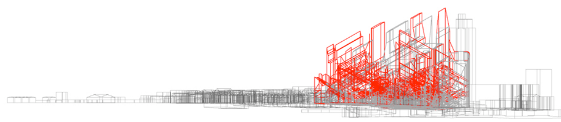
Figure 14: Comparison of accumulated solar irradiance at Linz-Pichling's SolarCity Masterplan (Sectors 1 - 5) and Manchester's Smithfield Market site (Seed Grids 3 & 4) during successional growth sequence. As a successional growth sequence did not take place during the development of SolarCity a linear measure of community solar irradiance is represented on the graph for each sector.

5. CONCLUSION

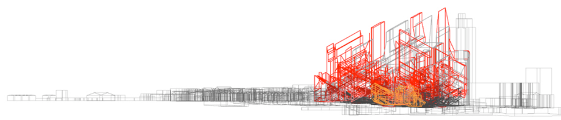
Irradiance analysis of forest-inspired growth has demonstrated that solar communities which intentionally occupy compact sites originally derived by non-solar factors have the potential to perform favourably against contemporary built sustainable developments. Further, as the total solar irradiance intercepted by any solar model, seeded randomly or otherwise, is the same, a shade-tolerant community has the potential to generate energy for diffuse daylight derived species that establish in later succession. The current methodology has been to quantify and express visually biomimetic growth at hourly solar time-checks i.e. 09.00, 12.00, and 15.00hrs. Further research not described here has extended this language with an investigation into the possibility of forest inspired solar that considers prolonged periods of solar and daylight access.

Through a process of Boolean modelling this hourly solar city would be transformed into a state of suspended animation or stasis, enabling the visualisation of a biomimetically stratified community more in tune with natural forest biorhythms and structure. As durational periods of solar and shade access are immediately realised a visual survey has confirmed that periods of solar insolation lengthen within the overstorey and the upper regions of the stasis canopy, while periods of shadow progressively increase nearer the understorey and ground.

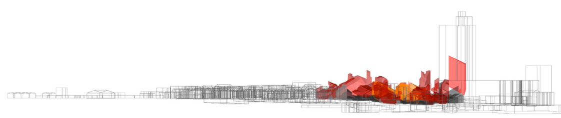
Though a conceptual shift from the highly theoretical (Cyclic community) to the tangible (Stasis community) incurred a substantial loss of insolated developmental volume (Fig. 15 & Fig. 16), economies of community energy use and space have allowed the possibility of an advanced stasis forest-inspired solar city, beyond the scope of this study - A nomadic community whose shade-tolerant and shade-intolerant species seasonally migrate between superimposed solar stratified layers.



(a) Cyclic community: 09.00hrs + 12.00hrs + 15.00hrs.



(b) Identification of volume intersections.



(c) Stasis community identified by Boolean intersections.

Figure 15: Generation of Forest-Inspired Solar Stasis, Miller Street site, North elevation, Equinox.

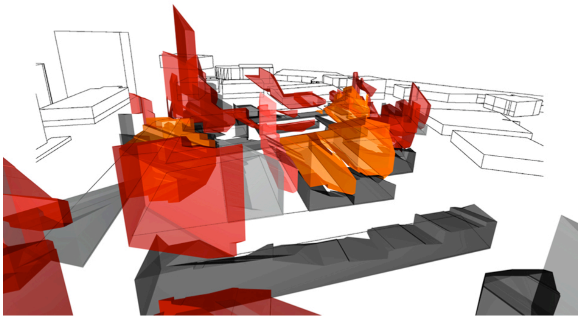


Figure 16: Light stratified system of forest-inspired growth in stasis.

FUTURE VISION

A futuristic vision of solar city migrating across a post-industrial city, continually adapting to changing environmental and programmatic contexts lends itself to an integrated Cellular Automata, Geographic Information System, and Spatially Explicit Individual-based growth simulator. The next phase of Plasti-City research will determine the possibility of such an integrated simulator that facilitates the automated generation of solar geometries, sets and evaluates environmental energy thresholds, and employs cell states (Plasti-City niche) to determine the carrying capacity of dispersed polycentric solar communities or interseasonal energy hubs by instructing dependent cells that cannot be solar sustained to change state and nomadically search for a new productive solar city landscape (Fig. 17).

Figure 17: A Mancunian Phenotypic Plasti-City undergoing an urban solar Polyclimax. Future growth is now reliant on an ability to be sustained by an ecological niche within a forest-inspired masterplan that adapts to daily and seasonal environmental forces and rhythms.

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Sernander's earlier observations of Scandinavian boreal forests concluded that storm gaps reaching 1000m^2 are necessary if shade-intolerant species are to become active. The reason being that an opening of this magnitude would allow approximately 80% of incoming diffuse light to reach the forest floor in contrast to 100m^2 patch size that only allows 20% penetration. Hence, disturbances larger than a single tree fall must take place in forests of narrow-crowned trees whose directional succession would without such disturbance tend towards a self-replacing climax of shade-tolerants.

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