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INTERNAL EXTENSIONS: A CASE FOR THE REASSESSMENT OF THE ARCHITECTURAL PHENOMENON OF GREENHOUSE

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INTERNAL EXTENSIONS: A CASE FOR THE REASSESSMENT OF THE ARCHITECTURAL PHENOMENON OF GREENHOUSE

ABSTRACT

Glasshouses, greenhouses, conservatories and orangeries – all types of buildings intended specifically for plant cultivation – represent a relatively recent addition to the histories and repertoires of horticulture, agriculture and architecture. During approximately three centuries of their notable existence, these structures managed to not only enable the growth of exotic plants removed far from their natural range but also to form a particular genre of architecture, which developed through different phases, from feeble experiment through high exclusivity to near irrelevance – and back into new paradigms of vegetation-culture-architecture relationship. Starting not only from historical/contemporary examples but also from the general promise of enclosed ecologies, this paper aims both to analyse the phenomenon of greenhouse, as well as to explore parameters and options for its further expansion along conceptual and design-oriented lines.

Keywords: *greenhouse, glasshouse, conservatory, nature presentation, programmatic integration*

1. HISTORY AND CONTOUR PROPOSITIONS

Plants create one of the most basic propositions of our experience of space. Additionally, vegetation – or "nature" as it is often simplified– represents the most basic context for architecture. Exceptions would amount only to climatic zones of extreme aridity, salinity or cold. Environments composed predominantly of built forms are also amongst those exceptions but are nonetheless often regarded as incomplete, barren and even inhumane – precisely due to the absence of vegetation. It is perhaps only the sky that "surrounds" architecture more often than plants. However, for most of the architectural history, plants and buildings (especially interiors of building envelopes) very rarely entertained any interconnectedness or close interaction. In classical antiquity, such connections, if built on a grand enough scale (that is, in royal interpretation), even qualified for a "world wonder" [1].

Basic reasons for this lack of interaction can be mostly attributed to (historical) limitations of building materials, building practices and overall economy:

- Built space has, almost permanently, been supremely resource-demanding, financially expensive and mostly in short supply.
- Traditional building materials, either in themselves, their connections and joints, or in appearance and air quality, have, for the most part, been incompatible with humidity that larger plant ensembles demand (but also transpire).
- Transparent and translucent materials – the prerequisite for any cultivation *inside* the envelope – had a very long and gradual history of establishing themselves to be anything more than a darkness-preventing device, let alone a source of adequate illumination for the growth of plants. The cost of these materials was initially prohibitive, but after a certain point, it proved to be a catalyst for the prestige-induced development of the historical greenhouse.

Observed through the lens of the aforementioned (historical) forces, the phenomenon / the idea - of a greenhouse does prove to be a pure progeny of the industrial age and, indeed, might be a distinct illustration of the ways in which industrial production transformed the idea of built space. However, despite these reasons being crucial - and some of the associated problems insurmountable - no less important was also the lack of specific cultural, political and ideological preconditions for the emergence of architectural-horticultural spaces. These preconditions have slowly started to emerge with the early modern period and the rise of two specific socio-cultural phenomena:

- Intense European exploration of the XV and XVI centuries, together with the fact that these (mostly naval) explorations were focused primarily on geographical areas with climatic conditions warmer than those found in Europe. From such locations, early (and later) explorers, often with some members of the crew versed in natural sciences, started to bring numerous seeds and live specimens of exotic plant life.
- Rise of the scientific method and worldview and, within it, the clear emergence of distinct disciplines such as botany. More abstractly, it was the age of Enlightenment, and the principal drive of unimpeded, "pure" reason at its core, that enabled - conceptually –plants to be decoupled from their original environments and (re)assembled within structures simulate only partial parameters of the original habitat, such as temperature and humidity.

- Much later, new narratives were also called for in the course of greenhouse building revivals of the 1960s/'70s and 2000s. For the seventies, those were narratives of emerging (geo)systemic scientific disciplines, while the most recent impulses relate to either the sustainability of food production or the conservation of biological diversity in an age of possible serious climatic disruptions. Possibly with less of a true invention with regards to the teleology of the greenhouse, this last chapter of the development testifies more to the significance of the legacy, as well as the aesthetic appeal of the previous era of enclosed botanical spaces.

With this expansion and rationalistic structuring of the European worldview achieved, technological advances in iron and glass manufacturing started to shape the classical glasshouse – or 'conservatory' – of the XIX century. Still being very expensive, especially in light of existing glass and window taxations in England, France, and other countries of Western Europe [2], the conservatory became the signalling device for wealth and social status. Initially being used for a wide variety of horticultural and social purposes, the glasshouse quickly became the prime focus for many botanical institutions, which had been in existence for decades and even centuries prior. Large conservatories, glasshouses, and palm houses (etc.) were erected in Kew, Paris, Brussels, Copenhagen, Berlin, Vienna, St. Petersburg, and New York, as well as in aristocratic estates, especially in Britain [3].

Figure 1. Glasshouses at the Royal Botanical Garden Edinburgh [4], displaying an array of periods and elements: on the left side is the Temperate Palm House (Matheson, 1858), with a substantial part of the solid-wall envelope (quite an unusual trait for the time, save for the orangeries of the previous era) and clearstory central nave for the tallest of species. This building is also the highest XIX-century conservatory in Britain [4]. To the rear is the octagonal Tropical Palm House (unknown architect, 1834). The right side of the photograph reveals the Front Range (main glasshouse range, architects A. Pandreigh and G. Pearce, 1960) with its hi-tech structural exoskeleton. Photo: Andrew Bowden, CC BY-SA 2.0 Deed license.

However, what seemed like a dawning of the evolution of the new architectural type (and even field) – coinciding precisely with the spirit and industrial capabilities of the time – proved to be its short and almost only true peak. It lasted only several decades, approximately from the 1830s to 1880s, and was perfectly exemplified by Joseph Paxton's non-horticultural edifice of 1851, where it promised both the new idea of space (and space

boundaries) as well as the technological might of continuous envelope expansion [5]. After nearly extinguishing itself by the end of the nineteenth century, the process left behind buildings in a relatively narrow stylistic range: cast- and wrought-iron girders, assembled for maximum span and embellished in high ornamentation (traditional in appearance but with few precise historical stylistic references) [3].

In this paper, based on and extended upon previously published research [6], we will aim to outline the conceptual boundaries of the phenomenon of horticultural-architectural space in the wide range of its designated programmes. We will explore reasons for the short-lived expansion of the XIX century and the logic (and possible inconsistencies) of the phenomenon's revival in recent decades. Further, we will try to construct the conceptual apparatus for understanding and designing the botanical-architectural space, where we will try to be guided by its history, its general components, recent examples and our own design explorations in the field. More so, we will propose that there is a specific programmatic and aesthetic field in architecture, which is based on (re)presentation of the botanical world. We find compelling reasons to increase clarity in this field since the recent inflation of vegetation-related concepts threatens to unnecessarily and regretfully collapse the "bubble" in a similar fashion to the way it happened at the end of the XIX century.

2. METHODOLOGY

The methodological approach has two aims in mind: First, to clarify the wider scope of the (historical) phenomenon of greenhouses, and second, to propose possible directions for design work in the field of enclosed ecologies and botanical collections. Clarification of the scope invites, first and foremost, a typological approach, especially in light of the wide diversity of forms and the different historical types that emerged throughout the development of the greenhouse—such as the orangery—besides the tracing of historical lines and the construction of historical narratives. Thus, we will construct two basic typologies: one stemming from the *programme* and the other from the *form* of the greenhouse. The form itself will be actually studied through the properties of the envelope, which in this kind of building bears disproportionately large significance in both aesthetic and technical sense.

The second part of the methodological procedure, being centred on design possibilities rather than on historical facts alone, proposes (in a substantially more open and free manner) some of the possible key design approaches. It does so by extrapolating upon the *omissions* recognised within the history of the conservatory: which general approaches were not there, which trends were not fully explored, what are unrecognised contemporary tropes, etc. However, any of the proposed directions would still be in conjunction with the core elements of the foundational typology, either in the programme or in the envelope.

3. PROGRAMMATIC TYPOLOGIES

Great botanical conservatories[1], as well as their small, private offshoots, are far from being the only – or even representative – forms of plants grown in enclosures. The broadest

[1] Note on terminology: "conservatory", "greenhouse" and "glasshouse" can often be used interchangeably, except when the applied materials dictate otherwise. "Glasshouse" is obviously inappropriate when glass is substituted with other translucent material. "Greenhouse" is the most general term, though it has its

typology, according to purpose, might be summed up through four broadest designations: general gardening, agriculture, special purposes and botany.

3.1. GENERAL GARDENING

These often combine several purposes but also remain present in many other types since interest in the practices of gardening and resulting ambientes are hardly ever absent from precisely designated botanical spaces. Also, it is in the (historical) nature of greenhouses – and, as we will argue later, perhaps regretfully so – to be overly universal and multifunctional in its spatial arrangement. Thus, many of them acquired their form from one intended use and transferred to another, even though some disadvantages were obvious and hardly ever resolvable. For example, the Nash Conservatory (arch. Nash 1825, rebuilt and adapted by Wyatville 1836) was originally built precisely to fit the category of "general gardening" as something more than a horticultural pavilion adjacent to Buckingham Palace [7]. Its classical architecture (a modification of the outer envelope of the peripteros) was as equally in focus as the exotic plants that it was intended to house. Due to inappropriate positioning on the northern side of the palace, and thus with insufficient light for plants, it was dismantled and rebuilt in Kew Gardens eleven years after the initial construction. There, it changed its botanical roles several times, with its possibilities limited both due to low height and too much solid envelope. Today, it serves auxiliary purposes [8], similar to many orangeries, which, despite our inclination to cautiously observe progressive linearities, probably at least somewhat represent a technological phase surpassed by the nineteenth-century classical greenhouse of iron and glass. (Orangeries will come again to the forefront later in the text.)

Exceptions, transitions and typological overlappings aside, greenhouses intended as a form of "enclosed garden" do exist as a type in itself, and their large overall range spreads from countless small conservatories (most often private, intended for growing of food, ornamentals and simply for pleasure), up to the royal ensembles built to impress by stature and show of horticultural form and colour, rather than by its botanical collection. A prime historical example of this end of the spectrum is perhaps found in the Royal Greenhouses of Laeken, which is a vast ensemble of different greenhouses on the premises of the court and royal gardens of Belgian monarchs. It was conceived and built during several decades (from the early 1870s to early 1900s), upon the wishes of King Leopold II and through his close collaboration with architect Alphonse Balat (and after Balat's death, with Henri Maquet and Charles-Louis Girault) [9]. It was not built as a structure completely devoted to housing endless collections of plants but as a set of representative spaces in a new architectural medium of transparent structures and materials: the "ideal glass palace", as the correspondence between the Balat and King Leopold suggests [10]. It was, at least in extrapolation and outcome, a collection of several new types of new architecture (including a chapel, the Iron Church), none of which served plants exclusively but integrated them into this new vision.

narrower connotation: small garden structure, often with glass alternatives. Here, interchangeable use is often only due to stylistic requirements of the text.

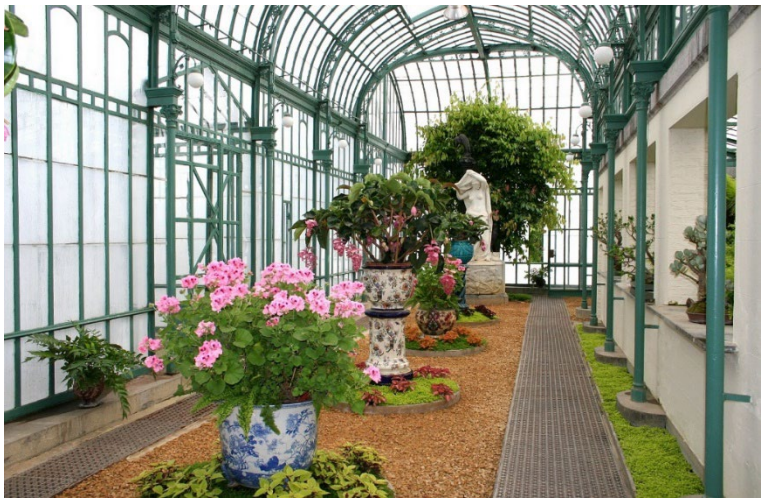


Figure 2. Interior of the Embarcadère Greenhouse, Royal Greenhouses of Laeken (arch. Alphonse Balat, 1874-1890). Photo: Jean-Pol Grandmont, CC BY-SA 3.0 license.

Historical accounts often mention the origins of controlled environment gardening as being a matter of courts and royal wishes and excesses. According to Pliny the Elder [11], physicians of Emperor Tiberius (ca. 30 AD) proposed to Caesar to eat a certain kind of vegetable (a cucurbite) every day of the year. Imperial gardeners achieved the task by devising carts that were drawn inside buildings by night, drawn outside by day – and on cold days, covered with semi-transparent mineral slates (selenite). Much later, in a different part of the world (but before any exact record of European examples), Korean royalty in 1450s also enjoyed a prolonged growing season of citrus trees housed in structures covered with *hanji* (a specific kind of oiled paper, made from inner bark of paper mulberry, *Broussonetia papyrifera*), heated with ondol (underfloor heating), with substantial thermal mass of several earthen walls [12].

Proper greenhouses and orangeries started to appear in Italy and Western Europe in the XVI and XVII centuries, mostly enticed exactly by gardeners (for citrus and other fruits, as well as for apothecaries) [13].

General gardening – for purposes of enhancing the ambience and character of architectural spaces - but also for the production and use of small amounts of food or flowers – remains today by far the most dominant form of horticultural-architectural space, from modest attached extensions in a residential context, through all kinds of “green” embellishments of commercial enterprises (including housing), up to large public projects for new or revitalised spaces.

3.2. AGRICULTURE

Outside of the scope of gardening and its multilayered interests, bulk production of food did not converge with the greenhouse for a very long time. It can be argued that the demise of glasshouses as architecture coincides with continued improvements in glass and iron/steel manufacturing, which, especially during the last decades of the XIX century, democratised ownership of conservatories, thus decreasing its allure as wealth signalling item [14]. These same improvements brought forth opportunities for the mass production of food, thus removing almost all practical limits to the spread of agricultural enclosed

environments. The greenhouse escaped the realm of architecture, first into only specific tasks of agriculture and, later, into becoming a significant force in shaping entire landscapes - like in the Netherlands (where glass as a material of choice still dominates) or south Spain (with polyethylene or other kinds of oil-derived translucent materials). Although now a much more widespread phenomenon, this was also an amplified echo of numerous historical examples of agriculture-driven large-scale built modifications of microclimate (and thus of local landscapes).

Figure 3. Contemporary landscape dominated by agricultural glasshouses: Westland, Netherlands. Photo: Tom Hegen, with permission.

Figure 4. A historical landscape dominated by agricultural controlled environments (heat-retaining walls, some with greenhouses): Montreuil-sous-Bois, suburbs of Paris. Photo: unknown author, public domain.

Figure 5. A historical landscape dominated by agricultural controlled environments (heat-retaining walls): Thomery, Île-de-France. Photo: Google Earth, Maxar Technologies 2023.

The past two decades have seen the reconceptualisation of elements of agricultural greenhouses as particularly useful to architecture, urban planning and sustainable design. High environmental costs of food production and transportation have produced many calls for the reintegration of urban life and agriculture/gardening [14]. New concepts of “urban farms” emerged, either as mono-thematic or overlapping with other architectural programs. Up until now, few have been built and put to (effective) production.

Figure 6. Agrotopia, an agricultural greenhouse with visitor and research facilities atop the agricultural market, Oostnieuwkerksesteenweg Roeselare, Belgium (van Bergen Kolpa Architects & Meta architectuurbureau, 2022). Photo: Filip Dujardin, with permission.

3.3. SPECIAL PURPOSES

During the second part of the XX century, specific qualities of light-admitting controlled environments attracted attention to experiments which surpassed individual disciplines such as botany or horticulture. Drawing both from theories of ecological microcosms [15], earth system science and the perceived need to develop a material and operational basis for outer space colonisation, distinct experiments were established in which broader (systemic) parameters of general climate, energy circulation, biological productivity and human integration were deemed more important for exploration, than researching and presenting individual species [16]. The most notable and the largest of these was the *Biosphere 2*, an air-tight complex of microbiomes (simulations of forests, mangroves, savannas, scrubs, deserts, etc.) under a large greenhouse with complex mechanical support systems. *Biosphere 2* (name suggesting its conceptual successor role for the “biosphere 1” – Earth) was built between 1987 and 1991, and in the early 1990s, this complex hosted a rather theatrical and less-than-ideal semi-scientific mission of several humans who lived inside, breathed inside closed circuits of oxygen and carbon, grew food and purified water for complete two years. It continues to serve a unique role among greenhouses today [17].

Figure 7. Biosphere 2*, a research facility in Oracle, Arizona (architecture Peter Jon Pearce et al., 1987-1991), currently run by the University of Arizona for Earth systems and closed ecological systems research, but initially envisioned by one of its founders, John P. Allen, as a vehicle of establishing ways to both repair the Earth's systems and enable life beyond them [16, 17]. Photo: Philéco 1, CC BY-SA 3.0 licence.*

Light-admitting and heat-retaining enclosed spaces do offer themselves for numerous other tasks, sometimes highly derived and quite innovative. For example, practices of ecological design, originating profusely in the 1970s, greatly emphasised the potentials of the greenhouse in many combinations (for example, animal husbandry with entrapment and use of residual animal heat [18]. Perhaps the most interesting, both technically and culturally, is the use of greenhouses for biological wastewater purification. Pioneered by John Todd, these systems used complex assemblies of many kinds of organisms (fungi, algae, bacteria, protozoa, up to molluscs, fish and higher plants – with plants being visually dominant and spatially most demanding). These would be assembled in purification sequences in order to use up the organic matter in wastewater or bind the inorganic pollutants. A controlled environment envelope would be indispensable for optimal and consistent functioning of such systems. In temperate or cold climates, the envelope would be continuous and translucent, but in the tropics, it would consist mainly of controllable shades [19]. The resulting appearance is that of a multifunctional greenhouse, where plants do dominate in size, but it is not strictly a botanical or horticultural structure, but a biological one in the sense of encompassing many kingdoms of life: plants, fungi, animals, bacteria, etc. It is also ecological in the sense of both spontaneous and purposeful arrangements of organisms into interconnected systems. Finally, it is also technological in the sense of having precise tasks, utilitarian boundaries and strict performance parameters. In addition, it represents an object with a wider cultural mission: to address usual (mis)understandings about water, pollution, the interconnectedness of life, and the vitality of natural systems. Todd's work resulted in the establishment of several smaller (often experimental) wastewater treatment facilities, but it also fundamentally influenced a specific niche in wastewater treatment technology. There, plants and glasshouses are being presented as tools for new urban integrations of these formerly unsightly technological facilities. The cultural significance of plants here is underscored by the fact that in contemporary systems of this kind, the biological treatment of wastewater by the plants and on the plant roots comprises a relatively small percentage of the overall process. The rest of the treatment occurs mostly on structures (meshes and similar) intended to host microbial activity at

lower depths in treatment pools, where plant roots do not reach in sufficient quantity. [20]. Thus, while not being indispensable, the plants (and with them, the greenhouses) remain the main trump card of those urban planning solutions in which the (waste) water cycle is accepted again into the city.

Figures 8. and 9. South Pest Wastewater treatment facility (Budapest, 2012, architecture: Organica Water, precise authorship unknown to us): Plants grown in a controlled environment assist in the process of aerobic/oxygenated fixed-film wastewater treatment.). Photo: Ognjen Šukalo

3.4. BOTANY

Botanical conservatory (understood *stricto sensu*) represents only a special purpose greenhouse if judged by predominance of use. Agriculture and general gardening cover most of the space and individual examples. Buildings which are devoted solely to most optimally presenting the widest range of botanical specimens and botanical taxa are comparatively rare. However, in terms of architectural achievements and paradigm framework, both historical and recent, it is botany (and its adjacent life science disciplines) which define the field.

There is a great degree of overlap between the botanical conservatory and the one for general gardening and amenity purposes. Differences are linear rather than discrete, but the main defining parameter probably remains the level – and the whole narrative – of information related to plants and their assemblies. In a somewhat wider perspective, although the aforementioned differences in practical examples might be linear, the conceptual differences between the simple amenity - on one side - and the possibility of referring to the whole kingdom of plants of the world – on the other – stand as quite stark and put botanically oriented concepts ahead of all previously explored programmatic types. It is mostly with this idea of *botanical representation* of the “corners of the world” that we will later propose new readings of a greenhouse as such and of its (new) opportunities.

Figure 10. Botanical garden of Padova (Italy) in XVI century lithograph: the Renaissance proclivity towards "ideal" urban forms meets the concept of a botanical garden as a representation of the world itself [21]. Circular outline, surrounded by water, with an inscribed square, subdivided by cardinal directions. Landscaping/architectural layout is attributed to both Andrea Moroni and Daniele Barbaro [22]. The right middle portion of the lithograph presents one of the earliest graphical depictions and probably one of the earliest European examples of a greenhouse [23]

3.5. PROGRAMMATIC TYPOLOGIES: SUMMARY

The growing of plants in contained environments initially started as a peculiarity of the uppermost social strata, as an exercise in providing for the culinary whims of the wealthy. As such, it has its origins in food production but was simultaneously engaged by the practice and culture of general gardening. This initial line of high-class gardening of edible exotics persisted for a long time (arguably until the arrival of relatively fast transportation of food) but has branched into four main lines:

1) General gardening for pleasure and delight. It was in later centuries democratised to form a wide range: from very large and exclusive (as in the example of Belgian monarchs of the XIX century) all the way down to innumerable small conservatories aimed for aesthetics, occasional fruit and even attractive winter microclimate for humans.

2) Mass/commercial food production entered the stage fairly late, only at the moment when the prices of materials and industrial capacities matched the enormous scale of agriculture. This scale continued to direct this particular line of development, easily surpassing the level of individual architectural buildings and spreading to whole landscapes instead.

3) The prospects of a growing environment that can be modified and controlled to a significant degree produced several narrowly focused uses of the greenhouse: experiments in outer space colonisation, water purification, etc.

4) Botanical conservatories branched very early, notably in the early modern period, with the rise of the first botanical institutions and apothecaries. However, it was with the European exploration and colonisation that larger plant ensembles were required. Thus, the ever-improving iron and glass manufacturing enabled the rise of one of the most emblematic new types of XIX-century architecture: the classic botanical conservatory.

4. ENVELOPE TYPOLOGIES

In regards to the way architectural-horticultural spaces are conceived and materialised, we propose a relatively simple set of parameters. First, a conservatory is, typically and historically, a rather simple structure – a bubble of sorts – which most often does not allow for complex internal structuring. Although this proposition is something that we might want to question in our conceptual enquiries later, the envelope remains infinitely more consequential than any aspect of internal structuring. Thus, after programming, the second (or it should have been the first) parameter of this typology pertains to the skin that is there either to let the sun in or to keep the heat in the appropriate range. Leaving conceptual and design concerns for later and for a different kind of discussion, we propose an envelope typology that strictly distinguishes between hard elements and those that permit the passage of light:

4.1. TYPE AND DEPLOYMENT OF LIGHT ADMITTING ENVELOPE

4.1.1. Translucent envelope being non-existent

This possibility pertains, for the most part, to the creation of favourable microclimates through the (partial) encirclement of plant-growing space by buildings, free-standing walls, depressions in the ground, etc. It offers relatively little in terms of increasing critical minimal annual temperatures. (For example, cloudy winter days with little solar gains, followed by a clear night sky, can result in temperatures similar to those outside of this microclimate.) [24] Still, there are possibilities for the advancement of growing conditions on the opposing side of the spectrum: developing extremely warm (and dry) conditions for proper fruiting or flowering of certain species (as well as for avoiding certain plant diseases).

Traditional walled growing enclosures (previously illustrated here by historical speciality-crop growing for Parisian markets) are the principal example, but there are examples of combined use of this approach even in the relatively recent large-scale botanical conservatories.

4.1.2. Translucent envelope being auxiliary

Most (older) historical examples revolve around this concept: Tender exotic (or out-of-season) plants do grow outside in favourable weather conditions but remain housed under translucent material in colder weather and/or by night. Initial (large and formal) European solutions for controlled-environment horticulture were orangeries, high-ceiling, high-aperture and multiple-door buildings intended for housing citrus (and other) plants during

winter or night. During warmer parts of the year, plants (in pots or other root containers) would be carted outside, often to be formally presented in designated park-like spaces adjacent to the building itself [25]. Similar to the previous category, solar orientation of the buildings and yards would be such as to maximise thermal and light gains. Versailles Orangerie, designed by Luis Jules Hardouin-Mansart and built from 1684 to 1686, represents one of the most prominent examples of this type of building (although being known for its inadequate light, non-ideal northwestern exposure and malfunctioning heating system). Smaller and simpler orangeries of a similar age exist in many other locations, with examples from Kensington (1705, Hawksmoor), Belvedere (Von Hildebrandt, 1714), Kew (1761, Chambers), Kuskowo (Argounov, 1764) and other across Europe and somewhat later North America [25]. Orangeries - in the sense of this typology: buildings whose envelope combines closed and translucent properties - certainly are somewhat of a "historical phase" of a "proper" greenhouse, determined by dictates of technological and material propositions of the age and were "surpassed" with advents of iron frames and cheaper glass. Still, their architecture is - in not just one sense - more substantial and in a safe continuum with other types of architecture, and has been unfortunately abandoned for a more "perfected" version. The last two centuries have failed to provide us with an adequate prominent example. The New Orangery at the Prague Castle (arch. Eva Jiřičná, 1998-2001) fits that category in name only and is, at least by our understanding of this subject, a classical greenhouse.

Figure 10. Orangery at Royal Botanical Gardens Kew (arch. William Chambers, 1761) currently serves as a restaurant. Photo: Benjamin Evans, public domain.

Figure 11: New Orangery, Prague Castle (arch. Eva Jiřičná, 1998-2001): the name is derived from the historical existence of a citrus-growing structure in the place on which this new building was constructed. In the typology presented herein, we maintain this example to be mainly outside of the (historical) scope of orangeris and, in fact, to represent precisely a greenhouse. Photo: Prazak, CC BY 2.5. license.

4.1.3. Buildings with significant translucent envelope – proper greenhouses

Since establishing itself during the middle two-quarters of the XIX century as the most dominant and prestigious form of controlled-environment-cultivation structure, the (non-agricultural) greenhouse was produced in numerous examples. It appears in wide scopes, both in terms of size (area, volume, height) and in terms of its representative intentions and qualities. This category certainly comprises the central theme of this paper and some of its history, which we have already discussed. Here, we will only note a certain trajectory of change in the nature of the envelope itself through the evolutions that have occurred during the period of renewed interest in the second part of the XX century and onward. At the centre of these changes lie the innovations in the design of a more translucent envelope, fewer construction members inside, larger spans and hemispheric spaces.

Being a child of the “long XIX century” (1789-1914), the conservatory certainly had to wait for tumultuous times of world wars and unstable interbellum to pass, then for more pressing concerns to be managed in the first decades after the Second World War, to arrive yet again at a prolonged period of stability and abundance. It belongs to prosperous times, and the construction of new greenhouses started again around the 1960s. However, a large gap has developed in technology and (quite a bit more) in architectural paradigms since the last time these kinds of buildings were made. New construction systems, new envelopes and new esthetics were to be developed and deployed. Perhaps one of the most illustrative examples of this emerging experimentation and its relation to history is the Front Range of the Edinburgh Botanical Garden.

The brief in the commissioning for this new piece of controlled-environment botanical horticulture was explicit in asking for zero internal structural members and maximum admittance of light. This second request certainly reflects the historical limitations of Edinburgh’s Temperate Palm House, a building with a substantial amount of hard materials in its envelope (see Figure 1), a sort of transitionary form between older orangeries and classic iron-supported greenhouses, but it also speaks well about considerations of local

climate of cloudy Scotland [26]. The solution (both by brief author E.E. Kemp and by architects Allan Pandreigh, George Pearce and John Johnson) was found in the concept of "exoskeleton", which might have originated exactly in the universe of greenhouses (in 1853 by Charles Macintosh [26]), but was also completely "of the times" in forming one of the earliest examples of high-tech architecture (see Figure 1).

The second part and the end of the XX century saw large botanical conservatories being constructed in some form of geodesic dome, but it also saw the acceptance of translucent materials other than glass. Most prominent examples include The Climatron (the greenhouse of the Missouri Botanical Gardens, arch. Murphy and Mackey 1960) and, much later, the Eden Project (arch. Grimshaw, 2001). These innovations were partially led by ambitions for both greater light penetration and increased energy efficiency: Replacement of heavy glass asks for fewer and smaller construction members, especially since single-panelled glass remains unacceptably inefficient at conserving heat, while multiple-panelled glass elements would add even more to the weight. Advancements can be considerable, such as in the Eden Project, where the main hexagonal elements span 11 meters due to the lightness of ETFE-insulated „pillows" and with proportionally very thin and scarce structural members [27]. However, new and prominent glass envelopes are still being constructed. Remaining issues with the thermal properties of glass are addressed either by the adequate placement of other elements of the envelope (see further: The Great Glass House by Foster and Partners) or by substantially less need for heat conservation (subtropical climate of Singapore's Garden by the Bay, Grant Associates et al., 2006-2012).

Figure 12: The Eden Project, Cornwall, UK (arch. Nicolas Grimshaw, 2001), the largest public/botanical greenhouse in the world. The envelope is comprised of a hexagonal-triangular tubular steel structure covered with inflated panels made of ETFE (ethyltetrafluoroethylene). Photo: Jürgen Matern, Creative Commons license BY-SA 2.5.

4.2. TYPE AND DEPLOYMENT OF NON-TRANSLUCENT ENVELOPE

Besides being important from the point of view of architectural composition, solid (and especially high mass) materials represent the valuable repository of heat, often gained in large quantities on clear days. This thermal mass enables moderation of temperature extremes – which might have been an uncommon concern of the XIX century classical conservatories, unheeding of the energy use at the time.

4.2.1. None – ground being the only hard material besides the skeleton

It is worth noting that the relationship between the ground and the upper translucent envelope can vary, from the ground being flat through constructing dug-ins on slopes (properly oriented, as in the classic passive solar design of the 1970s) to the construction of

greenhouses in depression. For example, Nicolas Grimshaw's Eden Project is constructed on top of an abandoned kaolin surface mine, while Norman Foster's design for Great Glasshouse of the National Botanic Garden of Wales (2000) creates intentional earth banks on the lower (especially northern) parts of the greenhouse.

Figure 13: The Great Glasshouse at the National Botanic Garden of Wales (arch. Foster and Partners, 1995-2000). Besides being surrounded by embankment as a whole, the building has several additional indentations across the section in order to provide opportunities for heat capture and microclimate formation. Photo: Col Ford and Natasha de Vere, CC BY 2.0 Deed license.

Figure 14: Muttart Conservatory in Edmonton, Alberta, Canada (1976, arch. Peter Hemingway). Excavated mounds provide both micro-climatic stabilisation and reduced energy use, as well as a finer relationship with the landscape. The translucent envelope efficiently shrinks into only four high points and almost minimal surface area. The ensemble significantly expands on entrenched notions of a greenhouse. Photo: WinterE229 Winterforce media, public domain.

4.2.2. Hard materials being integrated into the envelope

As a type, classic orangeries provide the most illustrative range of this integration: from solid materials dominating and forming inconspicuous (non-horticulture-related) architecture to roofs and other parts of the envelope dissolving into transparent glass domes. An important design consideration here becomes the ratio of thermal protection (provided by mass) to light penetration (provided, of course, by translucent materials)[24]. The aforementioned orangeries – the more enclosed ones - could do away with maximum light penetration due to the seasonal nature of their operation. Most of their plants were not tropical and thus had some form of dormant season, which, when acclimatised to temperate climate conditions, could be spent in less than ideally lit buildings.


Figures 15. and 16. (Half)greenhouse, Banja Luka, Republic of Srpska, Bosnia and Herzegovina (2011-2014, arch. Ognjen Šukalo) during construction of the heat-retaining northern wall and roof structure. Materials: earth, straw, wood, glass. Photo: Ognjen Šukalo.

4.2.3. Greenhouses attached to other buildings

Here, besides architectural composition (both visual and spatial-programmatic), the main subject becomes the thermal and ambient interdependence between the main (hard material) space and the attachment. Unlike attachment, the integration of greenhouse space with that of hard material architecture belongs to a different conceptual domain, and in this paper will be explored in the following sections.

4.3. ENVELOPE TYPOLOGIES: SUMMARY

In a classical sense - and for all practical purposes also today – the conservatory is comprised almost solely of the translucent envelope. However, upon an inspection of the historical development of this architectural phenomenon, it is easy to recognise specific phases with different ratios of the solid and hard envelope, borne out of technical necessities but directed towards very distinct architectural types and modes of operation – like in an example of orangeries. On the other end of the timeline, during the revival of the late XX and early XIX century, some limitations of the all-translucent envelope have been brought forward, while the mass of the non/translucent part was put to greater use, with not just technical but also aesthetical good results. Overall typology, dispersed throughout the historical timeline, consists of two parts: 1) type of light/admitting envelope and 2) type of non-translucent envelope.

Within the first category, there are three main variants/types:

a) Non-existent translucent envelope (growing in open sky microclimates),

b) Translucent envelope being auxiliary (like in an orangery where it admits light on dormant plants),

c) A “proper” greenhouse with a rich history of development in its appearance and structure.

The second category is comprised of two types:

a) Non-existent hard parts - except for the earth

b) Hard parts being integrated into the envelope, both conceptually and in terms of the thermal properties of the building. The main example is the dug-in

conservatory, with very prominent examples being built during the last decades of the XX century.

c) Greenhouses attached to other buildings.

5. CONCEPTUAL PARAMETERS AND POSSIBLE DESIGN AVENUES

I think one of the big architectural issues of the future is realizing the real significance of plants in human life. And the connection between plants and buildings can only get closer, I think.

Nicolas Grimshaw [27]

Enclosed – architectural, that is - spaces admitting enough light and providing enough room for not only plants but their whole assemblies to grow, clearly represent an addition to the historical *progress* of architecture. Such improvements - not in the sense of material improvements, but in the sense of paradigm expansion – might be relatively rare throughout the history of architecture. The world of vegetation accepted into the world of *shelter* seems to offer a promise upon which indeed has been acted but whose potentialities have hardly been exhausted.

Based on previously elaborated history and typology, herein we propose a matrix of parameters for the design of greenhouses as fully integrated elements and entities of architecture.

5.1. PROGRAMMATIC INTEGRATION AND SPATIAL DISPERSION

Despite attached greenhouses being an established genre for a considerable time, further integration still remains a fecund possibility – especially in the domain of plant assemblies intended for botanical presentations. Botanical conservatories have historically, almost exclusively, tended to be isolated programmes, spaces and forms (and this includes the attached version). Modernist, as well as more recent attempts, certainly made steps toward further integration, but mostly in some form of a ‘great hall’. A decent example of this approach is found in Sheffield Winter Garden (by Pringle, Richards, Sharratt, 2002), while New York’s Ford Foundation (Roche, Dinkeloo, Kiley, 1968) remains one of the earliest - and arguably one of the most successful - integrations of semi-botanical plant assemblies and large, unifying hall-like spaces in buildings not primarily related to plant-presentation or leisure.

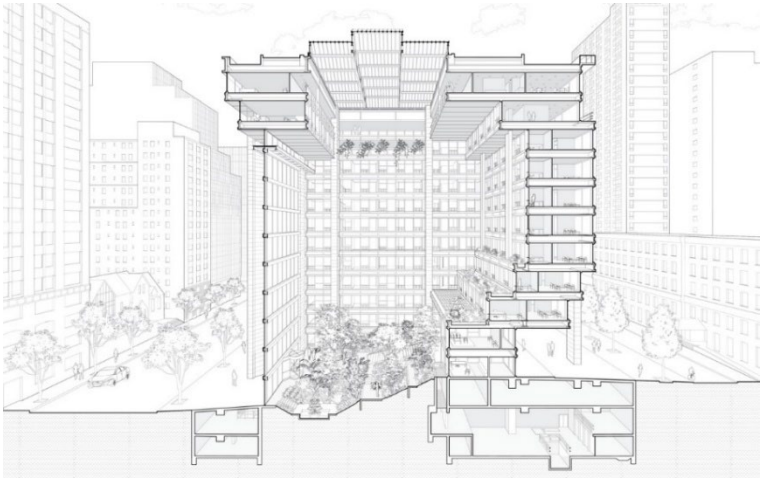
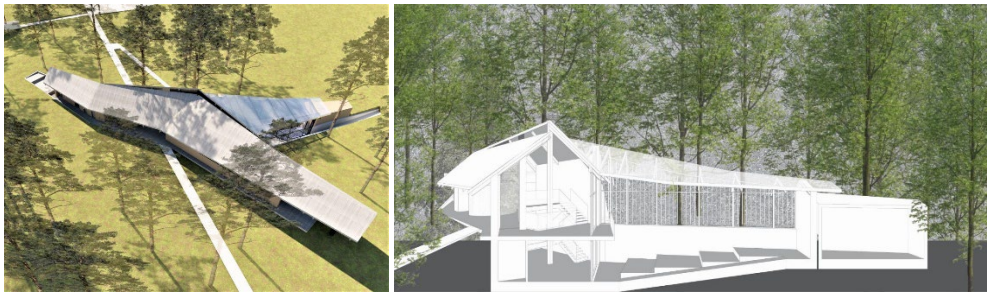


Figure 17: The Ford Foundation, New York (arch. Kevin Roche, const. John Dinkeloo, 1968), perspective section. Source: Lewis, P., Tsurumaki, M., Lewis, D.J.[28], with permission.

Indoor botanical presentations have predominantly tended to form ever more isolated units, which was based on both botanical categorisation/grouping as well as on needs for maintaining proper climatic conditions. These conditions can differ strongly in between, for example, spaces devoted to montane desert plants and those devoted to warm, humid environments. Further development of conservatory concepts emphasized these groupings based more on climate than strictly on botany. For example, the Princess Of Wales Conservatory at Kew (built in 1982-1986 by Arch. Gordon Wilson) contains as many as ten different climatic zones [29]. If this tendency to isolate space strictly along 'scientific' lines is modified, broad opportunities arise to weave botanical narratives with other architectural programs.



Figures 18. And 19.: Concept for the central building of Trapisti Arboretum, Banja Luka (arch. Ognjen Šukalo, Slobodan Peulić, Maja Milić Aleksić, 2020). General spatial disposition (figure 18) shows the glasshouse as an integral part of architectural form; its presentational function is continued into the solid envelope, which is, in turn, being transformed through a thin clearstory roof opening. The perspective section through the glasshouse and entry space (figure 19.) also displays the use of ground indentation for thermal as well as spatial reasons (lowering the building's profile while increasing the useful height). Ilustrations: Slobodan Peulić.

5.2. HEIGHT VS. GROUND

The dimensional range of different plant species is very broad – and it is conceptually relatable to a dimensional-programmatic range of human-built structures. Great conservatories, both contemporary and historical, have mostly responded to these botanical spatial requirements by creating spaces with a balanced spread of ground surface

to height – by creating, in the broadest sense, the hemispheric "bubbles". Variations, in XIX century examples, amounted mostly to the incorporation of basilical structural and spatial composition, which allowed for taller plants to stand in the central nave and smaller ones in aisles. Still, geodesic domes of the past several decades contributed to the homogenisation of the vertical-horizontal composition of the greenhouse. We believe it can be argued that this insistence on all-encompassing, even-spreading and homogeneous space greatly contributed to the architecture of conservatories rarely surpassing its ascribed domain of aristocratic folie or scientist's glassed garden. Differences in plant height – and, additionally, in root space requirements – offer a much more diverse and structured palette of elements for architectural composition. Here, the theme of ground should not be overlooked: the rooting space of smaller plants is much more architecturally malleable than the verticality of palms and trees.

Figure 20: Aiming for height: Klimatron *Conservatory of the Alexander Fomin Botanical Gardens in Kiev, Ukraine (1977, authors of architecture unknown to us). Photo: ArtemKo, CC licence 2.5.*

5.3. INTERNAL STRUCTURING

We have already observed that the phenomenon of enclosed horticultural space in almost every case aims not only for optimal penetration of the light through the "skin" of the structure but also eschews any hard-material blockages throughout its interior, like trying, in every instance, to enable light to travel to the centre of the aforementioned "bubble" and the ground. While this is mostly understandable from the point of view of single-programme building, any complex attempt at integration – which would take the greenhouse as its *starting point* – will necessarily have to navigate relationships of light and dark, space and boundaries *inside* of the main envelope.

Figures 21. And 22.: Coupling and "hybridisation" of two types. The greenhouse dominates in the outer envelope but is, in turn, internally structured. Sundby Naturhus, Sweden (2014, Tailor Made Akitekter). The Naturhus (natural house) concept of a house within a greenhouse was first extensively explored in the work of Swedish architect Bengt Warne in the 1960s and 1970s. Photo: Bjorn Wallentinus, Tailor Made Arkitekter and Greenhouse Living (general consultant).

5.4. LANDSCAPING CONTINUATION

There exists a relatively large range of species that might be non-native and not completely acclimatised to a particular (temperate) location of the greenhouse but which does not necessarily require enclosed spaces for these species to survive or even thrive. A microclimatic adjustment often suffices for these plants, and historical examples (for example, peaches in Île-de-France, but also of many botanical rockeries, alpinetums, domestic herb gardens etc.) abound. What perhaps lacks is a more consciously designed *continuum* of a greenhouse and on-the-ground modifications done with form, hard materials, walls and landscaping. Greenhouses need not always stand as sole "objects" imposed upon the surface of the landscape but may be an accent to the larger stretches of intervention.

5.5. OBJECT VS LANDSCAPES

Leaving (relatively) small botanical domain aside, we should pay additional attention to the main field of production of space in regards to enclosed horticulture – that of sprawling landscapes of agricultural greenhouses. Rather than excluding it from the scope of architecture (or viewing it only in terms of the "phenomena" to be researched), these landscapes can be recognised as a legitimate context of any architectural incursion. This seems especially valid in light of intensive (controlled environment) agricultural systems near or within urban centres having ever more importance for providing food for the growing population. It is in these "seas of glass" that solid-material architecture can play an organising role, especially in conjunction with pronounced verticality or visible, out-of-glass greenery.

6. CONCLUSION

The cultivation of plants in controlled environments – in greenhouses, conservatories, and glasshouses - has been a very specific architectural programme since its inception in the XVII or XVIII century. Different demands for light (compared to those related to human indoor use) have at first prevented this architecture from emerging, but later, with advancements in iron and glass production, it went through a few phases to create fully illuminated, completely glazed buildings. These buildings, having their first and highest peak in the XIX century, quickly created its somewhat simple and soon irrelevant genre– despite the ethos of the age being very favourable to glass as an instrument of architecture. A certain revival did appear from the 1960s onwards, but with high correlation to new types of construction (high-tech exoskeletons, geodesic domes, etc.) with still little scrutiny given to the exclusivity of the glass-only envelope and to the detriments of form-based only in geometry. The adoption of the greenhouse in commercial agriculture, with the resulting uncontrolled growth of its use, pushes this type of structure further away from generally accepted realms of architecture and complex design. (Recent explorations of urban agriculture did, however, provide some renewed interest and relevance.)

Starting with the presupposition that the basic tenets end elements of the idea of greenhouse promise substantially more than the history of its implementation has yet managed to provide, we proposed the structure for understanding this idea, as well as what could be, in our analysis, key design landmarks. Understanding begins with covering the basic domains of appropriate use of controlled horticultural environments, where historical dominants of gardening and agriculture are supplemented with special applications, such as constructed ecological systems for research, waste-water treatment, etc. This analysis places the historical flag-bearer – the botanical conservatory – only in the 'special' category but, in doing so, implies different quality and potentiality of narratives of botanical/climatic/ecological assemblies compared to those intended only for general gardening or amenity.

Analysis of essential spatial and material propositions determines the typology according to the nature and potentialities of different types of envelopes, starting from the main one – the ground. Distribution of hard envelopes proves to be undeservedly neglected, thus suggesting the direction for possible programmatic and design improvements. However, surpassing the mere remoulding of the mono-programmatic greenhouse, certain opportunities arise for (as of yet) sparsely explored cross-programme integrations. As the most promising among many, five conceptual parameters of integration are proposed for further expansion of the field:

A) rejection of the paradigm of the single, unified and maximised greenhouse space, or, in other words, suggestion for its dispersion or branching throughout other spaces and programs with which enclosed botanical spaces are being integrated;

B) malleability and expressive potential of markedly vertical plant spaces, along with the horizontal axes and pronounced adaptability of the concept – and spatial distribution – of growing ground.

C) Possibility and even necessity of more complex internal (hard) structuring of buildings which are potentially "hybrid" in nature but still based on the dominance of outer translucent envelope.

D) Continuation of larger strokes of design throughout, primarily landscaping but also potentially through auxiliary and other central buildings – in order for these landscaping elements to create a non-enclosed controlled growing environment and microclimates (while being in aesthetic concert with the glassed ones)

C) Acceptance of sprawling agricultural greenhouse landscapes as legitimate and interesting contexts for interpolations of solid-materials architecture.

In its most developed conceptual form, controlled environments containing exotic plants – organised and presented precisely as such (as ambassadors of biological and planetary riches from far away) – can play a role of secondary context. It would make for a complete additional layer of natural surroundings added to the one existing in the location. It also expands the notion of location, including orientations according not only to near and far surroundings but also to the place and role of buildings and humans in larger processes of the Earth.

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УНУТРАШЊЕ ЕКСТЕНЗИЈЕ: ИНИЦИЈАЛНА ПРЕИСПИТИВАЊА АРХИТЕКТОНСКЕ ФЕНОМЕНОЛОГИЈЕ СТАКЛЕНИКА

САЖЕТАК: Стакленици, ботанички конзерваторијуми и оранжерије – генерално, грађевине намијењене узгајању биљака – представљају релативно скорашњи додатак историјама и репертоарима хортикултуре, пољопривреде и архитектуре. Током приближно три вијека њиховог постојања у иоле развијеном облику, ове грађевине су успјеле, не само да омогуће узгајање егзотичних врста изван њиховог природног ареала, него и да успоставе посебан жанр архитектуре. Овај жанр развијао се кроз неколико различитих фаза: од крхког експеримента, преко високе ексклузивности, до скоро потпуне ирелевантности – уз постепени повратак са маргина помоћу нових парадигми односа између вегетације, културе и архитектуре. Полазећи, не само од историјских и савремених примјера, него и од општег обећања које пружају затворене екологије, овај текст настоји да испита феномен стакленика у тренутном стању, истовремено испитујући параметре и могућности за његов даљи развој у домену (архитектонског) дизајна.

Кључне ријечи: *стакленик, оранжерија, транслуцентност омотача, програмске интеграције.*