GDAŃSK UNIVERSITY
OF TECHNOLOGY

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Dyscyplina naukowa: Dziedzina nauk inżynieryjno-technicznych / architektura i urbanistyka

ROZPRAWA DOKTORSKA

Tytuł rozprawy w języku polskim: Regularność wizualna kompozycji fasad budynków mieszkalnych wielorodzinnych. Typologia wzorów, percepcja i ilościowe miary.

Tytuł rozprawy w języku angielskim: Visual regularity of the composition of multi-family residential building facades. Typology of patterns, perception, and quantitative measures.

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Gdańsk, rok 2025

Mojej żonie i córce

STRESZCZENIE

Streszczenie: Niniejsza rozprawa doktorska dotyczy regularności wizualnej kompozycji fasad współczesnych, polskich budynków mieszkalnych, wielorodzinnych w kontekście ich percepcji i preferencji estetycznych. Celem głównym pracy było zdefiniowanie typologii wzorców kompozycji elementów architektonicznych na elewacjach, poznanie preferencji Polaków względem tych wzorców oraz powiązanie ich z ilościowymi miarami regularności wizualnej, możliwymi do zastosowania w analizie i projektowaniu.

Rozprawa ma formę cyklu sześciu publikacji. W pierwszym etapie, na podstawie analizy siedmiu polskich realizacji nominowanych do nagrody im. Miesa van der Rohe, zidentyfikowano nieregularność wizualną jako jedną z cech charakterystycznych współczesnej architektury mieszkaniowej. W drugim etapie, dzięki parametrycznej analizie 113 fasad wyodrębniono sześć typów wzorów kompozycyjnych, które opisują sposób rozmieszczenia prostokątnych elementów (okna, balkony, panele) na elewacjach, tworząc formalny „alfabet” współczesnych kompozycji.

Kolejne etapy poświęcono ewaluacji typologii i regularności. W dwóch badaniach ankietowych (48 i 109 respondentów) wykazano, że regularność wizualna jest obiektywnie rozpoznawana i statystycznie istotnie powiązana z preferencjami estetycznymi – kompozycje bardziej regularne są oceniane jako bardziej atrakcyjne, przy jednoczesnym zróżnicowaniu ocen pomiędzy typami wzorów. Równolegle, w eksperymentach in silico na 245 oraz 343 syntetycznych kompozycjach opracowano i zweryfikowano dwa wskaźniki regularności bazujące na entropii Shannona: $H_{centerdist}$ oraz SVE_{DAS}. Wskaźniki te korelują z ocenianą regularnością wizualną odpowiednio na poziomie ok. 93% i 96% oraz z wysoką skutecznością porządkują pary kompozycji pod względem ich regularności.

Efektem aplikacyjnym pracy są dwa narzędzia typu open-source: skrypt do obliczania wskaźników regularności fasad oraz generator kompozycji o zadanym typie, parametrach architektonicznych i poziomie regularności. Wyniki rozprawy stanowią wkład w rozwój ilościowych metod analizy estetyki architektury oraz tworzą podstawy do dalszych badań nad kompozycją fasad, a także potencjalnych zastosowań w dydaktyce, praktyce projektowej, konkursach architektonicznych i planowaniu urbanistycznym zorientowanym na użytkownika. Ograniczeniem pracy jest skupienie na polskim mieszkalnictwie wielorodzinnym oraz dwuwymiarowych kompozycjach prostokątnych, co wyznacza kierunki przyszłych badań nad innymi typologiami funkcjonalnymi, formami elewacji i kontekstami kulturowymi.

Słowa kluczowe: regularność wizualna fasad; architektura mieszkaniowa; preferencje estetyczne użytkowników; algorytmiczne narzędzia projektowe; zrównoważone miasta i społeczności

Dziedzina nauki i techniki, zgodnie z wymogami OECD: Dziedzina nauk inżynieryjno-technicznych / architektura i urbanistyka

ABSTRACT

Abstract: This doctoral dissertation concerns the visual regularity of the composition of the facade of contemporary Polish multi-family residential buildings in the context of their perception and aesthetic preferences. The main objective of the work was to define a typology of compositional patterns of architectural elements on facades, to learn about Poles' preferences regarding these patterns, and to link them to quantitative measures of visual regularity that can be used in analysis and design.

The dissertation takes the form of a series of six publications. In the first stage, based on an analysis of seven Polish projects nominated for the Mies van der Rohe Award, visual irregularity was identified as one of the characteristic features of contemporary residential architecture. In the second stage, thanks to a parametric analysis of 113 facades, six types of compositional patterns were identified, which describe the arrangement of orthogonal elements (windows, balconies, panels) on facades, creating a formal “alphabet” of contemporary compositions.

The subsequent stages were devoted to the evaluation of typology and regularity. Two surveys (48 and 109 respondents) showed that visual regularity is objectively recognized and statistically significantly related to aesthetic preferences—more regular compositions are rated as more attractive, with varying ratings between pattern types. In parallel, in in silico experiments on 245 and 343 synthetic compositions, two regularity indices based on Shannon entropy were developed and verified: Hcenterdist and SVEDAS. These indicators correlate with the assessed visual regularity at a level of approximately 93% and 96%, respectively, and are highly effective in ordering pairs of compositions in terms of their regularity.

The practical outcome of the work are two open-source tools: a script for calculating facade regularity indices and a generator of compositions with a given type, architectural parameters, and level of regularity. The results of the dissertation contribute to the development of quantitative methods of architectural aesthetics analysis and lay the foundations for further research on facade composition, as well as potential applications in teaching, design practice, architectural competitions, and user-oriented urban planning. The limitation of the work is its focus on Polish multi-family housing and two-dimensional orthogonal compositions, which sets the direction for future research on other functional typologies, facade forms, and cultural contexts.

Keywords: visual regularity of facades; residential architecture; users' aesthetic preferences; algorithmic design tools; sustainable cities and communities

SPIS TREŚCI

1. WYKAZ PRAC WCHODZĄCYCH W SKŁAD ROZPRAWY

Publikacja I – Malewczyk, M; Czyż, P. 2022. „Features of irregularity in examples of Polish multi-family architecture constructed in 2011–2021 and nominated for the Mies van der Rohe award.” *Czasopismo Techniczne*, 119, 1-12, DOI: 10.37705/techtrans/e2022009

Link do Publikacji I

Publikacja II – Malewczyk, M; Taraszkiewicz, A; Czyż, P. 2022. „Composition Patterns of Contemporary Polish Residential Building Facades.” *Nexus Network Journal*, 24, 767-785, DOI: 10.1007/s00004-022-00614-y

Link do Publikacji II

Publikacja III - Malewczyk, M; Taraszkiewicz, A; Czyż, P. 2024. „Visual Perception of Regularity and the Composition Pattern Type of the Facade.” *Buildings*, 14, 1389, DOI: 10.3390/buildings14051389

Link do Publikacji III

Publikacja IV - Malewczyk, M; Taraszkiewicz, A; Czyż, P. 2022. „Preferences of the Facade Composition in the Context of Its Regularity and Irregularity.” *Buildings,* 12, 169, DOI: 10.3390/buildings12020169

Link do Publikacji IV

Publikacja V – Malewczyk, M. 2025. „The Mathematical Regularity Coefficient for Facade Patterns.” *Nexus Network Journal*, 27, 601-618, DOI: 10.1007/s00004-025-00827-x

Link do Publikacji V

Publikacja VI – Malewczyk, M. 2025. „Weighted Shannon entropy as a quantitative measure of façade pattern regularity.” *Zenodo*, DOI: 10.5281/zenodo.17534289

Link do Publikacji VI

2. WPROWADZENIE

2.1. Wstęp

Niniejsze opracowanie stanowi zbiór sześciu oryginalnych artykułów naukowych, w tym pięciu opublikowanych w wysoko punktowanych czasopismach naukowych. Cykl ten jest efektem projektu badawczego poświęconego kompozycji fasad budynków mieszkalnych, wielorodzinnych w kontekście ich percepcji, a przede wszystkim – regularności wizualnej. Praca ta odnosi się głównie do dwóch, bardzo szerokich problemów, wyraźnie zaznaczonych we współczesnej polskiej architekturze: problemu jakości zabudowy wielorodzinnej oraz problemu estetyki architektonicznej. W opinii autora cyklu opisywanego w niniejszej rozprawie, jak i autorów innych publikacji (Trębacz i Mazur 2020, Ulman i Ćwiek 2020), współczesna polska architektura wielorodzinna często jest niedopracowana i niedopasowana do oczekiwań jej użytkowników. Wskazuje to na istnienie istotnej luki pomiędzy deklarowanymi celami współczesnego projektowania a faktycznym doświadczeniem mieszkańców, w szczególności w zakresie jakości środowiska wizualnego.

W celu poprawy jakości mieszkalnictwa wielorodzinnego autor proponuje zastosowanie, w zakresie kształtowania kompozycji fasad, metody projektowej opartej ideowo na języku wzorców Christophera Alexandra (Alexander 1977). Oryginalny język wzorców to opracowanie stanowiące zbiór 253 gotowych, modelowych rozwiązań różnych problemów projektowych, opracowanych przez autorów książki. Idea ta jest jednak znacznie starsza od opracowania Alexandra. W podobny sposób kształtowano architekturę i urbanistykę od starożytności, bazując na wzornikach. Autor zakłada jednak nie tylko opracowanie nowych wzorców, ale także poznanie sposobu oddziaływania opracowanych wzorców na odbiorcę i zbudowanie na tej podstawie cyfrowego narzędzia projektowego. Tym samym proponowane podejście łączy tradycję „wzornikową" z nurtem współczesnych metod parametrycznych i algorytmicznych, nadając jej wymiar ilościowy i empirycznie weryfikowalny.

Niniejsza praca opiera się na założeniu, że istnieje skończona liczba wzorców projektowych kompozycji elementów architektonicznych na fasadach współczesnych budynków mieszkalnych, wielorodzinnych. Jednym z głównych celów pracy jest weryfikacja tej hipotezy, próba odkrycia owych wzorców kompozycji i ich ewaluacja. Proces realizacji celu został podzielony na cztery etapy, którym odpowiada sześć artykułów. W pierwszym etapie zidentyfikowano tendencje estetyczne w kształtowaniu współczesnej polskiej architektury wielorodzinnej (Publikacja I). Identyfikacji dokonano na podstawie analizy polskich realizacji wielorodzinnych, zrealizowanych w latach 2010–2020 i nominowanych do Nagrody im. Miesa van der Rohe, tj. obiektów uznanych za wartościowe i istotne dla kształtowania aktualnego dyskursu. W etapie drugim, na podstawie oceny parametrycznej 113 przykładów fasad, wyabstrahowano sześć wzorów kompozycji. W trzecim etapie poddano zdefiniowane wzory ewaluacji. Ewaluacji dokonano na podstawie dwóch badań ankietowych z udziałem ochotników oraz porównawczo – poprzez eksperyment obliczeniowy w środowisku in silico. W etapie czwartym dokonano praktycznej implementacji wyników i wniosków wyciągniętych na wcześniejszych etapach. Wyznaczono współczynnik matematyczny oraz narzędzia open-source, które pozwalają na oznaczenie regularności kompozycji elementów architektonicznych na fasadzie (lub innych, płaskich kompozycji, składających się z prostokątów), a także generator układów kompozycyjnych, stanowiących bazę do projektów elewacji.

W ten sposób praca sytuowana jest na styku teorii architektury, badań nad percepcją wizualną oraz metod ilościowych, proponując spójne ramy przejścia od opisu jakościowego („estetyka fasady") do mierzalnych parametrów kompozycji, możliwych do zastosowania zarówno w analizie istniejących realizacji, jak i w procesie projektowym.

2.2. Problematyka badawcza

Karsten Harries (1997) wyróżnia w swojej analizie historii architektury dwa obiekty kluczowe dla kształtowania całego dyskursu teoretycznego: świątynię i dom. Zgodnie z jego teorią, do XIX wieku to świątynia (rozumiana jako budynek ikoniczny – budynek sakralny, ale także np. budynek kultury) stanowiła najważniejszy przedmiot dyskusji. Po XIX wieku, na skutek przemian społecznych, gospodarczych, a także demograficznych, nastąpiło przewartościowanie. Przedmiotem dyskusji stał się dom jako symbol zamieszkiwania. Pojawiły się nowe teorie urbanistyczne, podejmujące temat osiedli mieszkaniowych – koncepcja miasta ogrodu (Howard 1902), koncepcja miasta przemysłowego (Garnier 1918), koncepcje modernistyczne (Le Corbusier 1968). Należy także zwrócić uwagę na silny wpływ modernizmu na rozwój myśli teoretycznej, związanej z samymi budynkami mieszkalnymi – np. zasad ergonomii (Neufert 1936), idei „maszyn do mieszkania" (Rosner 2020). Współcześnie mieszkalnictwo nadal jest jednym z najistotniejszych problemów dyskursu teoretycznego na temat architektury, co ujawnia się w badaniach nad codziennością (Upton 2002, Jacoby i Ozer 2024, Crawford 1999) i estetyką codzienności (Saito 2007, Mandoki 2007, Light i Smith 2005). W takim ujęciu dom i jego fasada stają się nie tylko obiektem funkcjonalnym, lecz także kluczowym nośnikiem znaczeń i doświadczeń codzienności.

Konieczność kontynuowania badań nad mieszkalnictwem jest bezsprzeczna, szczególnie w odniesieniu do architektury polskiej. Raport Ministerstwa Rozwoju i Technologii z dn. 5 marca 2020 roku wskazuje, że deficyt mieszkaniowy na koniec 2019 roku szacunkowo wynosił 650 tysięcy lokali mieszkalnych. Tak ogromny deficyt oznacza między innymi konieczność wybudowania wielu nowych budynków mieszkalnych, w tym wielorodzinnych. Tę tendencję potwierdza kolejny raport Ministerstwa Rozwoju i Technologii z dn. 24 stycznia 2022 roku. Według raportu, w 2021 roku oddano w Polsce najwięcej nowych mieszkań od 1979 roku. Surówka (2018) zdecydowanie wskazuje, że to właśnie deficyt mieszkaniowy jest głównym źródłem problemów polskiego mieszkalnictwa. Mamy w tym obszarze do czynienia z wieloma sytuacjami patologicznymi: substandardowe wielkości mieszkań, obchodzenie przepisów regulacyjnych, brak wystarczających warunków nasłonecznienia czy też braki infrastrukturalne (Węcławowicz 2015, Sokołowski 2023). Problematyczna jest także kwestia estetyki, która niejednokrotnie budzi wątpliwości co do jakości i celowości stosowania pewnych rozwiązań. W związku z powyższym można zadać pytanie, czy nowe obiekty wypełniające deficyt mieszkaniowy realizują potrzeby mieszkańców w należyty sposób? Pytanie to dotyczy nie tylko parametrów funkcjonalnych i użytkowych, ale również jakości środowiska wizualnego, którego jednym z głównych nośników jest kompozycja fasad.

Rolą i powinnością architektów jest zaprojektowanie budynków (także mieszkalnych) w jak najlepszy sposób. Budynki te powinny służyć ich przyszłym użytkownikom i pozwalać realizować ich potrzeby. Pisał o tym już Witruwiusz (1956) w pierwszym znanym współcześnie traktacie architektonicznym – jedną z cech architektury powinna być użyteczność (firmitas). Architektura według Witruwiusza powinna cechować się także pięknem (venustas). Piękno architektury, która stanowi materialne tło życia każdego człowieka, stanowi odpowiedź na jedną z ośmiu podstawowych potrzeb, zdefiniowanych przez Maslowa (2006). Piękno i użyteczność architektury są zatem ściśle powiązane, a realizowanie potrzeb estetycznych człowieka świadczy w pewnym stopniu o użyteczności dzieła architektonicznego. W tym sensie estetyka fasad nie jest jedynie „dodatkiem", lecz jednym z wymiarów funkcjonalności środowiska zbudowanego.

Od czego jednak zależy estetyka architektury? Według Roba Kriera (1988) jednym z najważniejszych czynników determinujących estetykę dzieła architektonicznego jest kompozycja fasady. Zgodnie z definicją encyklopedii PWN, kompozycja (łac. compositio 'złożenie', 'układ') to między innymi sposób powiązania elementów formalnych dzieła tak, by tworzyły całość zgodną z intencją twórcy. Pojęciem integralnie związanym z kompozycją jest tzw. schemat kompozycyjny, tj. stały układ elementów kompozycyjnych, charakterystyczny dla danego kierunku w sztuce czy epoki. Schematy kompozycyjne były jasno określone od starożytności. Przykładowo, w sztuce starożytnego Egiptu dominowała kompozycja pasowa, ściśle określone były także proporcje fasad świątyń greckich (Coulton 1975) oraz rzymskich (Witruwiusz 1956). To właśnie na podstawie proporcji dzieł starożytnych zdefiniowano zasady harmonii warunkujących piękno renesansowych dzieł architektonicznych (Alberti 1960). W ten sposób piękno warunkuje także Wielka Teoria Piękna (Tatarkiewicz 1972), która wiąże piękno z figurami i kształtami idealnymi (koło, kwadrat), złotym podziałem odcinka, złotą proporcją czy symetrią. Tego rodzaju proporcje odnalazł w wielu historycznych pomnikach architektury między innymi wspomniany wcześniej Rob Krier (1988). Tak rozumiane schematy kompozycyjne można traktować jako historyczne odpowiedniki współczesnych wzorców projektowych.

Celowość zastosowania języka matematyki w odniesieniu do kształtowania estetyki wynikała z potrzeby stworzenia uniwersalnych ram warunkujących piękno (Birkhoff 1936, Stewart 2007). Dostosowanie się do owych zasad pozwala zatem, w pewnym sensie, na wykreowanie obiektu, co do którego z góry wiadomo, jak będzie oddziaływał na odbiorcę. Model ten dobrze funkcjonował w historii w połączeniu z kolektywistycznym podejściem do twórczości, z twórczością operującą stylami architektonicznymi wypływającymi z jednorodnej myśli teoretycznej. Jednorodność twórczości, jednorodność stylów architektonicznych bazowała na jednorodnym podejściu do piękna, które było wartością absolutną, uwarunkowaną przez język matematyki.

Współcześnie piękno stanowi jednak bardzo silnie zrelatywizowaną kategorię estetyczną (Huemer i Vendrell 2018), a obowiązek kształtowania piękna przestał być obowiązkiem sztuki. Proces ten rozpoczął się stopniowo na początku XX wieku wraz z rosnącą rolą awangardy, aby ostatecznie osiągnąć kulminację w anty-estetycznej sztuce postmodernizmu (Foster 1998). Niemniej jednak także moderniści i postmoderniści architekci odnoszą się do klarownych wytycznych zawartych w traktatach architektonicznych i Wielkiej Teorii Piękna. Dowodem na to może być chociażby analiza proporcji współczesnej fasady ratusza w Murcji (Eardlay 2021), analiza modernistycznych dzieł Alejandro de la Soty (Sánchez 2016) i wiele innych (Càndito i Meloni 2022, Januszewski 2021). Twórcy analizowanych przykładów czerpią jednak z klasycznych proporcji w sposób indywidualny, niezależnie od współczesnej teorii czy doktryn projektowych. Piękno bowiem stało się relatywne, a zasady tworzenia piękna zależą od jednostki.

Pomimo wciąż obecnego postmodernistycznego, indywidualistycznego podejścia do projektowania architektury, można zauważyć wyraźne podobieństwa pomiędzy współcześnie projektowanymi budynkami (Wei i Shamir 2019, Yoshimura i inni 2019). W opinii autora nie do końca można podobieństwa te określić mianem stylu architektonicznego. Styl architektoniczny ma bowiem charakter odgórny, podbudowany jest myślą teoretyczną, doktryną filozoficzną, która definiuje estetykę. W przypadku współczesnej architektury homogeniczność estetyczna jest raczej oddolna i stanowi wynikową szeroko rozumianych uwarunkowań społecznych i projektowych. Należy tu zwrócić uwagę na dwa, wyraźnie ze sobą powiązane aspekty – globalizację oraz źródła inspiracji. Wszechobecne treści wizualne definiują myślenie i percepcję społeczeństwa obrazkowego, w tym architektów. Obrazy, zdjęcia i grafiki (często powiązane z działaniami marketingowymi) przenikają do ludzkiej podświadomości i zawężają widzenie i twórczość. Definiują, co odbiorcy się podoba, a co nie, skutkiem czego kolejne projekty stanowią, w pewnym sensie, kopię tych istniejących. Odtwarzamy fasady i detale, które widzieliśmy, traktując je czysto wizualnie. Zjawiska te mają bezpośrednie przełożenie na kompozycję fasad, które coraz częściej konstruowane są jako zestaw obrazów niż rezultat świadomej pracy nad strukturą.

Podobieństwa estetyczne współczesnej architektury są widoczne, zdaniem autora, przede wszystkim w obrębie kluczowego dla niniejszego opracowania mieszkalnictwa wielorodzinnego. Po pierwsze, ten rodzaj architektury jest bardzo mocno uwarunkowany przez zasady ergonomii, które wynikają wprost ze skali i proporcji człowieka. Determinuje to parametry takie jak wysokość kondygnacji, wielkość i rodzaj pomieszczeń czy elementy składowe budynku (np. balkony, okna w każdym pomieszczeniu mieszkalnym). Po drugie, mieszkalnictwo wielorodzinne jest także silnie uwarunkowane ekonomicznie. Wyraźne ograniczenia finansowe przekładają się na konieczność stosowania rozwiązań i materiałów typowych. Ograniczają możliwości konstrukcyjne (np. rozpiętości stropów, wysięg wsporników), a także możliwość stosowania zabiegów architektonicznych pozbawionych funkcjonalnego uzasadnienia. Po trzecie, architekturę wielorodzinną należy także rozpatrywać w kategorii produktu o wysokim stopniu komercjalizacji. Ponieważ zazwyczaj na etapie projektowym nie są znani docelowi mieszkańcy, ten rodzaj architektury musi operować rozwiązaniami jak najbardziej standardowymi. Rozwiązania typowe mają bowiem największy potencjał sprzedażowy, ponieważ odpowiadają potrzebom możliwie jak najszerszej grupy potencjalnych nabywców. W efekcie kompozycje fasad stają się kompromisem pomiędzy typizacją, kosztami a marketingowym „efektem wizualnym".

Konieczność odpowiedzi na powyżej omówione uwarunkowania, wpisania się w schematy i spełnienie oczekiwań deweloperów oraz indywidualistyczne, postmodernistyczne podejście projektowe przyczyniają się do powstania sytuacji problemowej. Architektura jest bardzo często projektowana i postrzegana stricte wizualnie. Jej produktowe znaczenie wymusza dodatkowo nieustanne poszukiwanie nowej estetyki, która jednak porusza się w tych samych uwarunkowaniach i nie posiada żadnej ponad-estetycznej treści. Tom Dyckhoff nazywa tę architekturę architekturą „wowhausu" (2018). Jej celem jest szokować, wyróżniać się i przykuwać uwagę. Nie jest jednak możliwe wyróżnianie się z masy stworzonej z innych wyróżniających się elementów. Skutkuje to chaosem przestrzennym, w którym użytkownik nie wie, jak ma się odnaleźć.

Powyższy stan rzeczy nie jest zjawiskiem nowym. Stanowi pośredni skutek narastającego od początku XX wieku rozwoju społeczno-gospodarczego oraz boomu informacyjnego, którego doświadczamy od momentu narodzenia telewizji oraz przede wszystkim internetu. Pojawiające się jednak od początku XIX wieku nowe koncepcje filozoficzne zwiastują nadejście nowej perspektywy teoretycznej. Koncepcje po-ponowoczesne, takie jak metamodernizm, altermodernizm, performatyzm, hipermodernizm czy nowy urbanizm przeciwstawiają się teorii postmodernistycznej i zwracają uwagę na społeczną rolę sztuki i architektury (Vermeulen i van der Akker 2010, Schwarte 2014, Garde 2020). Jurgen Habermas w wykładach „Modernizm – niedokończony projekt" (1996) oraz „Modern and Postmodern Architecture" (1998) wzywa wprost do odnowy architektury zorientowanej na społeczeństwo. Także Karsten Harries (1997) zwraca uwagę na etyczną wartość architektury. W tym kontekście problematyka estetyki fasad budynków mieszkalnych nabiera wymiaru etycznego i społecznego, wykraczając poza poziom czysto formalny.

Istotnym dla kształtowania architektury po-ponowoczesnej są także koncepcje dotyczące codzienności. Należy tu zwrócić uwagę na obecność nowego prądu estetyki, tj. estetyki codzienności. Ten obszar filozofii skupia się przede wszystkim na wydarzeniach codziennych i doświadczeniach człowieka podczas codziennych czynności. Już w 1974 roku Yi-Fu Tuan podkreślał konieczność zwrócenia uwagi na środowisko jako obiekt oceny estetycznej. Crispin Sartwell w 1995 roku rozwinął to myślenie i zaproponował odniesienie estetyki do samego życia. Yuriko Saito (2007) zaś zwraca uwagę na konieczność dokonywania osądów moralnych i estetycznych w odniesieniu do przedmiotów codziennego użytku, przestrzega jednak przed komercjalizacją. W ten sam sposób wypowiada się Rob Walker (2008), który krytykuje związek designu z wolnym rynkiem i nadużywanie wartości dodanej przez projektanta do celów stricte marketingowych.

Postulowana przez koncepcje po-ponowoczesne emancypacja potrzeb człowieka w kontekście całego społeczeństwa, a także wzrost zainteresowania codziennością stanowi, w opinii autora, wielką nadzieję dla poprawy jakości mieszkalnictwa wielorodzinnego. Niniejsza dysertacja stanowi próbę realizacji tych idei i propozycję zaangażowania potencjalnych użytkowników w proces projektowania celem zweryfikowania ich potrzeb. Jednym z wymiarów owego zaangażowania jest poznanie preferencji estetycznych oraz świadomość na temat sposobu percepcji architektury. Nie jest to jednak możliwe bez ustrukturyzowania wiedzy na temat samego projektowania i określenia ram projektowych w postaci wzorów czy typologii w odniesieniu do poszczególnych składowych architektury. Istotą jest bowiem wprowadzenie użytkownika już na etapie przedprojektowym, a nie poznanie jego opinii dopiero na temat skończonego projektu. Stąd potrzeba wypracowania języka kompozycji, który byłby jednocześnie zrozumiały dla projektantów i możliwy do empirycznego powiązania z preferencjami użytkowników.

Konieczność wprowadzenia użytkownika do procesu kształtowania estetyki architektonicznej można poprzeć chociażby badaniami przeprowadzonymi w 2012 roku (Montanana, Llinares, Navarro) oraz 2019 roku (Safarova, Pirko, Jurik). Ich wyniki wskazują na różnice w ocenie estetyki budynków przez grupy architektów i nie-architektów. Z jednej strony pokazują, że słusznym jest założenie, iż to architekci jako specjaliści powinni autorytarnie determinować estetykę budynków, niejako narzucając ją odbiorcom. Autorytarność ma w tym wypadku na celu podnoszenie standardów estetycznych. Z drugiej zaś strony, rozbieżność w sposobie postrzegania i w ewaluacji jakości estetycznej obiektów architektonicznych mogą skutkować projektami, które nie będą we właściwy sposób odpowiadać na potrzeby użytkowników. Historia architektury bogata jest w tego rodzaju obiekty. Przykładem może być chociażby cała architektura brutalistyczna, która z jednej strony była bardzo wyrafinowana i wyjątkowa pod względem estetycznym, z drugiej zaś – spotkała się z ogromnym niezrozumieniem społecznym (Niebrzydowski 2021, Waid i inni 2023, Jenkins 2024).

Należy także zwrócić uwagę na liczne opracowania z obszaru psychologii. Wnioski z nich wypływające sugerują, że relatywizowanie piękna nie do końca jest słuszne. Istnieje wiele mechanizmów i procesów neurobiologicznych, które warunkują procesy percepcji wzrokowej w sposób uniwersalny dla populacji ludzkiej (Zeki 1999). Przede wszystkim zjawiska związane z odczuciami towarzyszącymi obcowaniu z przedmiotami i dziełami sztuki są mierzalne. Rzeczy piękne, estetyczne pobudzają w mózgu ośrodek nagrody, zatem wywołują konkretną, biologiczną reakcję (Vartanian i Goel 2004, Kawabata i Zeki 2004, Cela-Conde i inni 2004, Markiewicz 2009). Konkretne obszary mózgu są także odpowiedzialne za percepcję regularności wizualnej (Biederman 1987, Kayaert i inni 2005, Amir i inni 2011). Bodźce regularne natomiast są postrzegane wyraźnie bardziej pozytywnie niż te nieregularne (Pecchienda i inni 2014, Taylor 2003, Taylor i inni 2005, Friedenberg 2021, Beramini i inni 2013). Wyniki te uzasadniają próbę ilościowego uchwycenia regularności wizualnej jako parametru potencjalnie powiązanego zarówno z oceną estetyczną, jak i z komfortem percepcyjnym użytkowników. W dalszej części pracy regularność wizualna zostanie zatem zoperacjonalizowana za pomocą wskaźników opartych na entropii Shannona ciągów odległości pomiędzy elementami kompozycyjnymi, co pozwoli traktować ją jako zmienną mierzalną, podatną na analizę statystyczną i implementację w narzędziach projektowych.

Podsumowując, współczesna polska architektura wielorodzinna znajduje się w sytuacji problemowej, wynikającej przede wszystkim z bardzo dużego deficytu mieszkaniowego oraz silnych uwarunkowań ekonomicznych. Nie bez znaczenia jest także fakt, iż znajdujemy się w luce pomiędzy wyeksploatowanym już postmodernizmem a ciągle kształtującymi się nowymi koncepcjami filozoficznymi. Jednym z wymiarów tejże sytuacji problemowej jest estetyka owych budynków, przejawiająca się w dużej mierze w kompozycji ich fasad. Zastosowanie wzorców projektowych w celu poprawy jakości architektury wielorodzinnej wydaje się być logicznie zasadne i posiada długą tradycję, zakutą we wzornikach architektonicznych. Poznanie preferencji potencjalnych użytkowników względem ustalonych wzorców z pewnością stanowiłoby wartość dodaną, a informacje na ten temat można by uznać za konkretne wytyczne dla projektanta. Osiągnąć powyższy cel można dwojako – poprzez badania statystyczne oraz zrozumienie uniwersalnych procesów, które warunkują percepcję. Tym samym możliwe jest pośrednie zaangażowanie przyszłych użytkowników architektury i zwiększenie szans na właściwą realizację ich potrzeb estetycznych (a potencjalnie – także innych). Niniejsza dysertacja wpisuje się właśnie w ten kierunek, koncentrując się na jednym, kluczowym wymiarze estetyki – regularności wizualnej kompozycji fasad oraz jej powiązaniu z percepcją i preferencjami estetycznymi.

2.3. Teza i cel pracy

Cel główny pracy

Głównym celem pracy jest zdefiniowanie typologii wzorców kompozycji elementów architektonicznych na elewacjach polskich, współczesnych budynków wielorodzinnych oraz poznanie preferencji polaków względem tychże wzorców. Celem uzupełniającym jest powiązanie zidentyfikowanych wzorców z ilościowymi miarami regularności wizualnej, co umożliwia ich zastosowanie w analizie i projektowaniu.

Cele szczegółowe pracy

I Określenie cech charakterystycznych współczesnej, polskiej architektury mieszkaniowej, wielorodzinnej w kontekście zagadnienia regularności wizualnej.

II Zdefiniowanie typologii wzorców kompozycyjnych fasad współczesnych, polskich budynków mieszkalnych wielorodzinnych.

III Określenie percepcyjnego stopnia regularności zdefiniowanych wzorców kompozycyjnych.

IV Określenie preferencji estetycznych polaków względem zdefiniowanych wzorców kompozycyjnych oraz stopnia regularności kompozycji.

V Wyznaczenie współczynników matematycznych opisujących regularność wizualną kompozycji.

VI Stworzenie narzędzia cyfrowego, generującego kompozycje zgodnie z określoną typologią oraz o określonym poziomie regularności.

Zestaw powyższych celów tworzy logiczny ciąg: od diagnozy i typologii, poprzez badania percepcji i preferencji, aż po zaproponowanie formalnych wskaźników regularności oraz ich implementację w postaci narzędzi cyfrowych.

Pytania badawcze

Pytania badawcze obejmują pięć powiązanych obszarów:

(1) rolę nieregularności w architekturze mieszkaniowej (pytanie I),

(2) typologię kompozycji elewacji (pytania II.I–II.II),

(3) percepcję regularności (pytania III.I–III.IV),

(4) preferencje estetyczne (pytania IV.I–IV.IV) oraz

(5) kwantyfikację regularności z wykorzystaniem współczynników matematycznych (pytania V.I–V.II).

I Jaką rolę odgrywa nieregularność wizualna we współczesnej, polskiej architekturze wielorodzinnej?

II.I Czy istnieją wyraźne cechy wspólne, pozwalające grupować kompozycje fasad współczesnych, polskich budynków wielorodzinnych?

II.II Jak często występują poszczególne typy kompozycji?

III.I Czy istnieje związek pomiędzy typem kompozycji a stopniem regularności?

III.II Jakie typy kompozycji są najbardziej, a jakie najmniej postrzegane jako regularne?

III.III Czy stopień regularności kompozycji fasady zależy jedynie od typu kompozycji?

III.IV Czy sposób prezentacji fasady ma wpływ na postrzeganie stopnia regularności kompozycji?

IV.I Czy istnieje związek pomiędzy stopniem regularności kompozycji fasady a preferencjami estetycznymi?

IV.II Czy kompozycje regularne są postrzegane jako bardziej estetyczne niż te bardziej nieregularne?

IV.III Czy istnieje związek pomiędzy typem kompozycji a preferencjami estetycznymi?

IV.IV Jaki typ kompozycji jest preferowany najbardziej a jaki najmniej?

V.I Czy istnieje współczynnik matematyczny, opisujący regularność wizualną kompozycji elementów architektonicznych na fasadzie?

V.II Jaka jest korelacja pomiędzy współczynnikiem matematycznym, opisującym regularność wizualną kompozycji elementów architektonicznych na fasadzie a percepcyjną regularnością wizualną poszczególnych typów kompozycyjnych?

Pytania te tworzą spójną matrycę badawczą, w której kolejne poziomy – od opisu, poprzez klasyfikację i percepcję, aż po kwantyfikację – są ze sobą ściśle powiązane i wspólnie prowadzą do realizacji celu głównego.

Teza pracy

Tezą niniejszej rozprawy jest, że kompozycje fasad współczesnych polskich budynków wielorodzinnych dają się opisać skończoną typologią wzorców, a stopień ich regularności wizualnej – wyrażony za pomocą współczynników opartych na entropii Shannona – jest istotnie skorelowany zarówno z percepcyjną oceną regularności, jak i z preferencjami estetycznymi użytkowników.

2.4. Układ pracy

Niniejsza praca składa się z cyklu publikacji. Sześć publikacji pozwoliło na realizację sześciu celów szczegółowych i udzielenie odpowiedzi na odpowiadające im pytania badawcze. W punkcie trzecim niniejszego opracowania zamieszczono komentarz do publikacji zamieszczonych jako załączniki w punkcie czwartym. Opracowanie zamyka punkt piąty, stanowiący podsumowanie.

Tak ukształtowany układ pracy odzwierciedla logikę procesu badawczego: od zarysowania problematyki i celów, poprzez charakterystykę oraz omówienie poszczególnych publikacji, aż po syntetyczne wnioski, odnoszące się do całości cyklu.

3. KOMETARZ DO PRAC

3.1. Publikacja I

Pierwsza praca oryginalna pt. „Features of irregularity in examples of Polish multi-family architecture constructed in 2011-2021 and nominated for the Mies van der Rohe award", opublikowana w Technical Transactions, stanowi wprowadzenie do kolejnych artykułów. Niniejszy tekst poświęcony jest analizie polskich budynków wielorodzinnych, zrealizowanych w latach 2011–2021 i nominowanych do nagrody im. Miesa van der Rohe. Autorska analiza została przeprowadzona na potrzeby weryfikacji hipotezy, która zakłada, że jedną z wiodących cech determinujących kompozycję współcześnie projektowanych fasad jest nieregularność. Publikacja ta odpowiada przede wszystkim na pytanie badawcze I oraz stanowi podstawę dla dalszej eksploracji roli nieregularności wizualnej w architekturze mieszkaniowej.

Badanie zostało poprzedzone przeglądem literatury poświęconym zagadnieniu nieregularności. W pierwszej kolejności zdefiniowano pojęcie nieregularności jako konsekwencję odrzucania zasad regularności. Jednocześnie nieregularność to ekstremum pewnej skali, gdzie z jednej strony znajdują się struktury w pełni uporządkowane (regularne), a z drugiej – chaotyczne (nieregularne) (Rubinowicz 2000). W odniesieniu do sztuk wizualnych regularność stanowi konsekwencję stosowania zasad zawartych w traktatach architektonicznych (Alberti 1960) oraz Wielkiej Teorii Piękna (Tatarkiewicz 1972), tj. symetrii, złotego podziału czy opierania się o figury idealne.

W kolejnym etapie dokonano analizy pojęcia nieregularności w trzech kontekstach. Po pierwsze, zagadnienie to rozpatrywano w kontekście kategorii estetycznej. Zgodnie z trendami i doktrynami panującymi w sztuce do XX wieku nieregularność była powiązana z brzydotą, jednakże awangarda oraz prądy takie jak turpizm (Stolnitz 1950) odwróciły tę tendencję. Po drugie, nieregularność przeanalizowano także w kontekście filozofii cywilizacji Zachodu, stawiając tezę, że nieregularność jest w pewnym sensie esencją współczesnego społeczeństwa. Nieregularność rozpatrywana w ten sposób odzwierciedla indywidualistyczne i liberalne trendy w opozycji do tych tradycyjnych, ustrukturyzowanych i konserwatywnych (regularnych). Po trzecie, nieregularność doskonale wiąże się ze wschodnią filozofią wabi-sabi, której istotą jest akceptacja przemijania i niedoskonałości (Korea 1994).

Dalsze rozdziały publikacji poświęcone są autorskiej analizie przykładów architektury. Przeanalizowano siedem realizacji mieszkaniowych, wielorodzinnych. Budynki zostały oddane do użytkowania pomiędzy 2011 a 2021 rokiem i nominowane do nagrody Unii Europejskiej im. Miesa van der Rohe. Obiekty wybrano do badania ze względu na walory architektoniczne oraz bezsprzeczny wpływ na kształtowanie współczesnego mieszkalnictwa wielorodzinnego. Analiza polegała na identyfikacji cech nieregularności w odniesieniu do trzech płaszczyzn estetyki architektonicznej: formy, materiału oraz kompozycji.

Badanie wykazało, że w przypadku każdej z trzech płaszczyzn estetycznych cztery na siedem przykładów przejawiały cechy nieregularności. Co jeszcze ważniejsze, każdy z analizowanych przykładów przejawiał takie cechy przynajmniej w odniesieniu do jednej z trzech płaszczyzn. Wyniki badania, chociaż odnoszą się jedynie do siedmiu wybranych realizacji, to ze względu na rangę owych obiektów, według autora, pozwalają mówić o pewnej tendencji w kształtowaniu współczesnej architektury wielorodzinnej w Polsce. Należy jednakże wziąć pod uwagę, że analizowane obiekty zostały uznane przez specjalistów w dziedzinie architektury. Nie jest znane stanowisko społeczeństwa względem tych obiektów, a także samej tendencji estetycznej opartej o nieregularność. Publikacja I pełni zatem funkcję rozpoznania wstępnego – identyfikuje problem nieregularności jako cechy charakterystycznej współczesnych realizacji, lecz równocześnie ujawnia potrzebę dalszych badań empirycznych nad percepcją i oceną tych zjawisk przez użytkowników.

Ograniczeniem badania jest niewielka liczebność próby oraz ekspertowy charakter doboru obiektów, co utrudnia generalizację wyników na cały zasób współczesnego budownictwa wielorodzinnego. Zidentyfikowana tendencja stanowi jednak ważny punkt wyjścia dla kolejnych analiz, w których nieregularność jest już rozpatrywana w szerszych próbach i w powiązaniu z percepcją użytkowników.

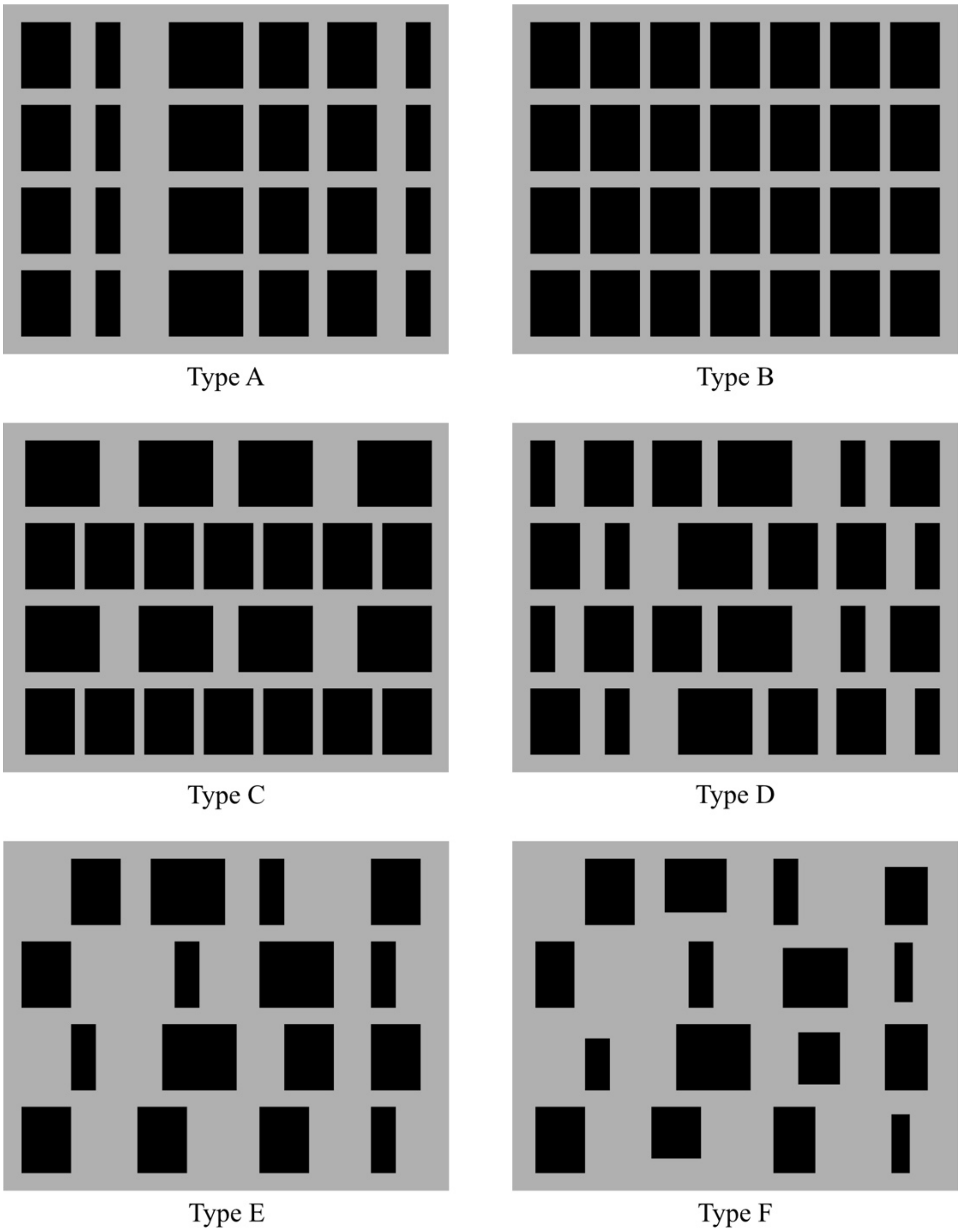
3.2. Publikacja II

Druga publikacja pt. „Composition Patterns of Contemporary Polish Residential Building Facades", wydana w Nexus Network Journal: Architecture and Mathematics, to praca oryginalna, której celem było zdefiniowanie typologii wzorów kompozycji fasad współczesnych budynków mieszkalnych, wielorodzinnych. Badanie zostało oparte o parametryczną analizę 113 budynków mieszkalnych, wielorodzinnych, oddanych do użytkowania pomiędzy 2018 a 2021 rokiem. Publikacja ta realizuje przede wszystkim cele szczegółowe II oraz częściowo I, odpowiadając na pytania badawcze z grupy II.I-II.II.

Część oryginalna została poprzedzona przeglądem literaturowym poświęconym trzem zagadnieniom kluczowym dla niniejszej publikacji. Pierwszym zagadnieniem jest sama kompozycja architektoniczna. Przegląd literatury wykazał, że kompozycja była tematem mocno ukonstytuowanym teoretycznie w odniesieniu do architektury historycznej. Współczesne opracowania nie stanowią jednak wyraźnych wytycznych projektowych, a mogą służyć raczej jako zbiór ogólnych praw i inspiracji. Kolejnym zagadnieniem jest temat oceny parametrycznej architektury pod względem jej jakości estetycznej. W szczególności zwrócono uwagę na metodę Birkhoffa, która jednak może zostać zastosowana w odniesieniu do obiektów istniejących lub gotowych projektów. Trzecim zagadnieniem jest typizacja i powtarzalność budownictwa wielorodzinnego, która wynika z zasad ergonomii, ekonomii, ale i globalizacji.

Autorskie badanie zakładało przede wszystkim weryfikację hipotezy, że istnieją wyraźne cechy wspólne łączące kompozycje analizowanych budynków w grupy (typy). Celem było także udzielenie odpowiedzi na dwa pytania badawcze, tj. czym charakteryzują się typy kompozycji i jak zostały zaprojektowane oraz jak często dane typy występują. Celem badania nie była ocena jakości oraz sposobu percepcji owych typów.

Badanie zostało przeprowadzone na podstawie zdjęć oraz wizualizacji 113 polskich budynków mieszkalnych, wielorodzinnych, oddanych do użytkowania pomiędzy 2018 a 2021 rokiem. Obrazy stanowiły załączniki do wszystkich ofert sprzedaży lokali mieszkalnych dostępnych na portalu Otodom.pl. Jest to najpopularniejszy tego typu serwis w Polsce (Zieliński 2019). Celowość wyboru źródła materiału badawczego wynikała z założenia, że powinien to być materiał jak najszerszy, a jednocześnie nieprzefiltrowany i niepoddany jakiejkolwiek ewaluacji (jak miałoby to miejsce w przypadku portali lub publikacji poświęconych architekturze). Materiał badawczy poddano cyfrowej obróbce, która miała na celu zsyntetyzowanie obrazów cyfrowych i przekształcenie ich w czarno-białe grafiki, reprezentujące kompozycje konkretnych elementów kompozycyjnych na fasadach analizowanych budynków (elementów takich jak okna, balkony czy panele). Ostatnim krokiem była analiza diagramów kompozycyjnych pod kątem relacji, jakie kształtują się pomiędzy elementami (np. odległości, powtarzalność, wymiary elementów).



Ryc. 1. Sześć przykładowych kompozycji, stworzonych zgodnie z typologią sześciu wzorów kompozycji (A–F) opracowaną przez autora na podstawie analizy 113 fasad.

Na podstawie wyników autorskiej analizy wyabstrahowano sześć typów kompozycji (Ryc. 1), które definiują wszystkie kompozycje zawarte na fasadach analizowanych obiektów. Roboczo typy te oznaczono literami od A do F. Opracowana typologia stanowi zestaw gotowych do zastosowania wzorów, rozumianych zgodnie z językiem wzorców Alexandra (1977). Typologia ta stanowi także punkt wyjścia dla publikacji III, IV oraz V. W szerszej perspektywie badanie to dostarcza formalnego „alfabetu” wzorów kompozycyjnych, który może być wykorzystywany zarówno w analizie istniejących budynków, jak i w generatywnych narzędziach projektowych.

Jednocześnie badanie to obarczone jest ograniczeniami: materiał pochodzi wyłącznie z jednego portalu ogłoszeniowego, a analiza operuje na zsyntetyzowanych rzutach dwuwymiarowych, abstrahując od kontekstu urbanistycznego i materiałowego. Typologia ma zatem charakter celowo uproszczony, co z jednej strony ogranicza jej zakres, z drugiej jednak ułatwia jej wykorzystanie w dalszych, ilościowych analizach i narzędziach generatywnych.

3.3. Publikacja III

Trzecia publikacja pt. „Visual Perception of Regularity and the Composition Pattern Type of the Facade”, wydana w czasopiśmie Buildings, to praca oryginalna, której celem było zweryfikowanie, w jaki sposób postrzegana jest regularność wizualna dwuwymiarowych kompozycji architektonicznych, w odniesieniu do zdefiniowanej w Publikacji II typologii kompozycji. Badanie zostało przeprowadzone w formie ankiety internetowej, przeprowadzonej w grupie 48 respondentów. Publikacja III realizuje przede wszystkim cele szczegółowe III oraz częściowo II, odpowiadając na pytania badawcze z grupy III.I-III.IV.

Opis badania oraz dyskusję wyników poprzedzono analizą pojęć kluczowych w kontekście współczesnych tekstów naukowych. Skupiono się tu w pierwszej kolejności na relacji piękna z kompozycją. Przywołano szereg prac z zakresu psychologii percepcji, neuroestetyki i teorii projektowania, m.in. autorstwa Arnheima (1977), Langa (1987), Bovilla (1996), Ramachandrana (1999), Zekiego (1999) czy Chinga (1996). Szczególną uwagę zwrócono na rolę fraktali, symetrii i porządku geometrycznego w kształtowaniu wrażeń estetycznych oraz na neurologiczne podstawy preferencji dla struktur regularnych. Podkreślono również, że nadmierna monotonia, mimo swojej regularności, może negatywnie wpływać na percepcję architektury, a nawet zdrowie psychiczne odbiorcy, co sugeruje potrzebę równowagi między porządkiem a złożonością. Drugim pojęciem, na którym skupiono się w części teoretycznej, jest regularność. Zdefiniowano ją jako kontinuum między pełnym porządkiem a całkowitym chaosem, przy czym percepcja tej cechy ma charakter obiektywny i biologicznie uwarunkowany.

Badanie miało charakter empiryczny i zostało przeprowadzone w formie ankiety wśród 48 losowo dobranych respondentów. Zespół badawczy celowo wyeliminował wpływ takich czynników jak perspektywa, materiały czy skala, koncentrując się wyłącznie na czystej kompozycji jako nośniku regularności wizualnej.

W badaniu postawiono cztery pytania badawcze:

1. Czy istnieje związek między rodzajem kompozycji elewacji a stopniem jej regularności?
2. Które typy kompozycji są najbardziej regularne, a które najmniej?
3. Czy stopień regularności kompozycji elewacji zależy tylko od rodzaju kompozycji?
4. Czy prezentacja bodźców w różnych konfiguracjach wpływa na określenie stopnia regularności?

Badanie zostało przeprowadzone w grupie 48 respondentów i miało formę dobrowolnej, anonimowej ankiety internetowej. Informacja o ankiecie została przesłana do studentów Architektury oraz Gospodarki Przestrzennej na Wydziale Architektury Politechniki Gdańskiej. Celem respondentów było ocenienie prezentowanych kompozycji na skali Likerta. 12 kompozycji było poddanych ocenie dwukrotnie, w różnych konfiguracjach. Wyniki badania ankietowego poddano analizom statystycznym. Wykonano obliczenia dla jednokierunkowej ANOVY wraz z testami post hoc oraz przeprowadzono procedurę GLM (procedura statystyczna do analizy powtórzonych pomiarów).

Analiza wyników obliczeń statystycznych wykazała wyraźny związek pomiędzy percepcyjnym stopniem regularności a typem kompozycji. Typy A oraz C postrzegane są jako najbardziej regularne, B i D posiadają umiarkowany stopień regularności, a E oraz F są postrzegane jako najmniej regularne. Jednocześnie wykazano, że typ kompozycji to nie jedyna jej cecha, która odpowiada za regularność wizualną. Nie bez znaczenia jest także kontekst, w jakim kompozycja jest prezentowana (co potwierdza wcześniejsze badania publikowane przez innych autorów). Publikacja ta stanowi zatem pomost pomiędzy czysto formalną typologią (Publikacja II) a dalszymi próbami kwantyfikacji regularności (Publikacje V i VI), pokazując, że „typ kompozycji" jest silnie, lecz nie wyłącznie, powiązany z odbieraną regularnością.

Za istotne ograniczenie należy uznać stosunkowo niewielką liczebność próby oraz fakt, że znaczną część respondentów stanowili studenci kierunków architektonicznych, co może wpływać na strukturę odpowiedzi. Celowe uproszczenie bodźców (abstrakcyjne kompozycje pozbawione materiału i kontekstu) ogranicza możliwość bezpośredniego przełożenia wyników na ocenę realnej zabudowy, ale pozwala precyzyjnie odizolować wpływ samej kompozycji.

3.4. Publikacja IV

Czwarta publikacja pt. „Preferences of the Facade Composition in the Context of Its Regularity and Irregularity", wydana w czasopiśmie Buildings, to praca oryginalna, której celem było zbadanie preferencji społeczeństwa polskiego względem kompozycji fasad w zależności od stopnia regularności i nieregularności. Badanie zostało przeprowadzone w formie ankiety internetowej, przeprowadzonej w grupie 109 respondentów. Publikacja ta realizuje przede wszystkim cel szczegółowy IV, odpowiadając na pytania badawcze IV.I-IV.IV oraz rozwijając wątek powiązania regularności z oceną estetyczną.

Część oryginalna została poprzedzona wstępem oraz przeglądem literaturowym, które stanowią niejako powtórzenie i podsumowanie informacji zawartych we wstępie niniejszej dysertacji oraz pierwszych trzech publikacji. Zdefiniowano pojęcie estetyki, odniesiono się do nieregularności estetycznej jako istotnej cechy determinującej współczesną architekturę, a także do badań z dziedziny psychologii eksperymentalnej na temat postrzegania nieregularności wizualnej. Zwrócono także uwagę na aspekt obiektywności i uniwersalności procesu postrzegania piękna, bazując na wynikach badań neuropsychologicznych.

Głównym celem autorskiego badania było określenie preferencji Polaków w zależności od stopnia regularności kompozycji i jednocześnie udzielenie odpowiedzi na cztery pytania badawcze:

1. Czy istnieje związek między stopniem regularności kompozycji elewacji a preferencjami estetycznymi?

2. Czy regularne kompozycje są uważane za bardziej estetyczne niż te o większym stopniu nieregularności?

3. Czy istnieje związek między rodzajem kompozycji a preferencjami estetycznymi?

4. Jaki rodzaj kompozycji jest preferowany najbardziej, a jaki najmniej?

Badanie zostało przeprowadzone w grupie 109 respondentów i miało formę anonimowej, dobrowolnej ankiety internetowej. Informacja o ankiecie została umieszczona na platformie facebook.com i została upowszechniona przy pomocy narzędzia do promowania postów. Wiadomość została udostępniona osobom w wieku 18-65 lat, deklarującym zamieszkanie w Polsce. Procedura stanowiła replikację wcześniejszych badań o podobnym charakterze (Safarova 2019, Graham i Gifford 2001). Głównym zadaniem ankietowanych było uszeregowanie pięciu fasad budynków od najbardziej do najmniej estetycznej. Materiał badawczy to autorskie wizualizacje komputerowe, przedstawiające fasady budynku. Fasady różniły się jedynie kompozycją oraz zróżnicowaniem szerokości otworów okiennych. Kompozycje zostały oparte o typologię opracowaną i zaprezentowaną w Publikacji II niniejszego cyklu. Ze względów wydawniczych posłużono się jednak inną nomenklaturą (Publikacja IV ukazała się wcześniej niż Publikacja II). Jedna fasada została oparta o kompozycję typu X, tj. A według Publikacji II, dwie fasady zostały oparte o kompozycję typu Y oraz Z, tj. odpowiednio B oraz E według Publikacji II. Ponieważ głównym celem badania było określenie preferencji estetycznych względem stopnia regularności, bodźce stworzono w ten sposób, aby wyraźnie odróżniały się od siebie pod kątem regularności.

Analiza zebranych wyników wykazała, że istnieje wyraźny związek pomiędzy stopniem regularności kompozycji oraz preferencjami estetycznymi. Ponadto wyniki wskazują na zależność, że to kompozycje regularne postrzegane są jako te bardziej estetyczne. Warto nadmienić, że kompozycje nieregularne wywołują silniejszą reakcję negatywną niż bodźce regularne – pozytywną. Naturalnie jest to potwierdzenie efektu, który został już w psychologii udowodniony (Baumeister 2001). Preferencje estetyczne zależą także od typu kompozycji, co jest naturalną konsekwencją wyników zaprezentowanych w Publikacji III. Zauważono także, że zdecydowanie bardziej pozytywne emocje budzą kompozycje oparte o jasno zbudowane pionowe osie kompozycyjne, złożone z jednakowych elementów ustawionych jeden ponad drugim. Publikacja IV dostarcza tym samym bezpośredniego empirycznego uzasadnienia dla tezy, iż regularność wizualna nie tylko jest rozpoznawana, ale także preferowana przez znaczną część badanej populacji.

Ograniczeniem badania jest dobór próby oparty na ochotnikach rekrutowanych za pośrednictwem mediów społecznościowych oraz operowanie na wizualizacjach komputerowych pojedynczej fasady. Uzyskane wyniki należy zatem interpretować jako diagnozę tendencji w deklarowanych preferencjach, a nie pełny obraz postaw całej populacji. Z drugiej strony szeroki wiekowy i liczebny zakres próby pozwala uchwycić istotne, statystycznie wyraźne zależności pomiędzy regularnością kompozycji a oceną estetyczną.

3.5. Publikacja V

Piąta publikacja pt. „The Mathematical Regularity Coefficient for Façade Patterns", wydana w czasopiśmie Nexus Network Journal, to praca oryginalna, której celem było zweryfikowanie hipotezy zakładającej istnienie współczynnika matematycznego, którym można opisać regularność wyżej wymienionych kompozycji. Badanie przeprowadzono na 245 kompozycjach, stworzonych przez autora na podstawie 49 przykładów architektury – obiektów nominowanych w 2024 roku do nagrody im. Miesa van der Rohe w kategorii mieszkalnictwo zbiorowe. Publikacja V realizuje przede wszystkim cel szczegółowy V oraz częściowo II i III, odpowiadając na pytania badawcze V.I-V.II.

Przegląd teoretyczny pracy skupia się na analizie dwóch kluczowych, dla niniejszej publikacji, pojęć – regularności wizualnej i jej percepcji oraz metod analizy regularności obrazów. Autor odwołuje się do prac z zakresu neurologii oraz psychologii, między innymi Kubiliusa, Wagemansa i Op de Beecka (2014), Biedermana (1987), Kayaerta i innych (2005), Amira i innych (2011) czy też Bertaminiego i innych (2013). Publikacje te zwracają uwagę na obiektywny charakter postrzegania regularności wizualnej, co wynika z biologicznych podstaw jej percepcji. Tym samym dowiedziono zasadności wyznaczania współczynnika matematycznego, który miałby opisywać regularność kompozycji. W kolejnej części autor skupia się na analizie metod analizy regularności obrazu, głównie przy wykorzystaniu pojęcia entropii w ujęciu teorii informacji. W szczególności istotne są tu prace Güzelci i innych (2020, 2021), Güzelci i Alaçam (2019), Cromptona (2012) czy Stampsa (2012, 2014). W pracach tych także wykorzystywano teorię entropii Shannona do badania architektury, chociaż w innych kontekstach.

Jak już wspomniano, głównym celem pracy było wyznaczenie współczynnika matematycznego, którym można by było opisać regularność kompozycji elementów architektonicznych na fasadzie. Postawiono zatem dwa pytania badawcze:

1. Czy istnieje współczynnik matematyczny, opisujący regularność wizualną kompozycji elementów architektonicznych na fasadzie?

2. Jaka jest korelacja pomiędzy współczynnikiem matematycznym, opisującym regularność wizualną kompozycji elementów architektonicznych na fasadzie a percepcyjną regularnością wizualną poszczególnych typów kompozycyjnych?

Materiał badawczy stanowiło 245 kompozycji prostokątów, symbolizujących otwory okienne czy też panele elewacyjne. 49 kompozycji zostało stworzonych bezpośrednio na podstawie zdjęć fasad 49 realizacji architektonicznych, nominowanych do nagrody im. Miesa van der Rohe, edycja 2024 w kategorii mieszkalnictwo zbiorowe. Pozostałe 196 kompozycji powstało poprzez modyfikacje ww. układów. Następnie, przy pomocy skryptu komputerowego, dla każdej z kompozycji dokonano wyliczenia 30 wskaźników matematycznych, bazujących na zmienności statystycznej oraz entropii Shannona.

Analiza statystyczna wyników badania pozwoliła na wyabstrahowanie wskaźnika matematycznego, który koreluje z regularnością wizualną kompozycji stanowiących materiał badawczy w 93% przy zmienności poniżej 10%. Wskaźnik ten ($H_{centerdist}$) zdefiniowano jako entropię Shannona ciągu, stworzonego przez bezwzględne odległości pomiędzy środkami elementów kompozycyjnych (prostokątów). Jednocześnie wykazano, że typologia wzorów kompozycyjnych, która została opracowana w Publikacji II, koreluje z regularnością wizualną na poziomie 71%. Wynik ten potwierdza rezultaty badania opisanego w Publikacji III, w której to ustalono korelację pomiędzy regularnością wizualną kompozycji a jej typem na poziomie 68%.

Dodatkowym efektem Publikacji V było stworzenie narzędzia cyfrowego, które pozwala obliczyć wskaźnik $H_{centerdist}$ dla dowolnej, płaskiej kompozycji, składającej się z prostokątów. Narzędzie wraz z kodem źródłowym udostępniono poprzez platformę Most Wiedzy na zasadach open-source. Publikacja ta stanowi zatem pierwszy krok w kierunku przełożenia jakościowego pojęcia regularności wizualnej na konkretny, operacyjny wskaźnik ilościowy, możliwy do stosowania w praktyce analitycznej i projektowej.

Należy podkreślić, że zastosowana metoda zakłada istotne uproszczenia: analizie poddawane są wyłącznie kompozycje prostokątne, abstrahuje się od materiału, kolorystyki i głębi przestrzennej, a regularność opisana jest pojedynczym wskaźnikiem. Ograniczenia te zawężają zakres bezpośredniego odniesienia wyników do złożonych fasad rzeczywistych, ale równocześnie umożliwiają precyzyjne testowanie zależności pomiędzy strukturą geometryczną a odbieraną regularnością.

3.6. Publikacja VI

Szósta publikacja pt. „Weighted Shannon entropy as a quantitative measure of façade pattern regularity" to preprint metodyczny, opublikowany w serwisie naukowym Zenodo.org. Artykuł ten to praca oryginalna, która dokumentuje ulepszoną wersję metody badawczej opisywanej na łamach Publikacji V. Głównym celem było zweryfikowanie hipotezy zakładającej, że współczynnik ważonej entropii Shannona (SVE – Shannon Variance Entropy) będzie dokładniej opisywał regularność kompozycji elementów na fasadzie aniżeli współczynnik $H_{centerdist}$ opisywany na łamach Publikacji V. Celem dodatkowym było zweryfikowanie hipotezy o możliwości zastosowania współczynnika matematycznego, opisującego regularność wizualną kompozycji, jako funkcji celu w cyfrowych narzędziach generujących wzory fasad. Badanie oparto o metodologię opisaną na łamach Publikacji V, jednakże rozszerzono próbkę badawczą z 245 do 343 kompozycji, stworzonych przez autora na podstawie tych samych 49 przykładów architektury, których użyto w Publikacji V. Publikacja VI rozwija zatem cele szczegółowe V i VI, koncentrując się na precyzji wskaźnika oraz jego implementacji w procesach generatywnych.

W niniejszej pracy podjęto próbę udzielenia odpowiedzi na cztery pytania badawcze:

1. Jak matematycznie zdefiniować optymalną funkcję, łączącą entropię Shannona z miarami wariancji przestrzennej?

2. Jakie parametry kompozycji fasad (wielkości elementów kompozycyjnych, odstępy, położenie) najsilniej wpływają na opracowywany wskaźnik SVE?

3. Jak wskaźnik SVE koreluje z regularnością wzorów fasad i czy korelacja ta jest silniejsza niż w przypadku pierwotnego wskaźnika $H_{centerdist}$?

4. Czy jest możliwe algorytmiczne generowanie wzorów fasad poprzez odgórne określenie parametru SVE?

Właściwe badanie poprzedzono przeglądem teoretycznym, w którym skupiono się na analizie trzech, kluczowych dla niniejszej publikacji, pojęć. Pierwszym z nich jest zagadnienie miar regularności w architekturze. Autor zwraca uwagę przede wszystkim na rosnące zainteresowanie metod ilościowych w ww. kontekście (Stiny i Mitchell 1978, Ilgaz i inni 2025, Med'dahi i Boussora 2021). Drugim pojęciem kluczowym jest pojęcie entropii Shannona oraz kontekst jej zastosowań, co częściowo pokrywa się z przeglądem teoretycznym zawartym w Publikacji V. Istotną nowością jest analiza pojęcia entropii ważonej, która uwzględnia nie tylko prawdopodobieństwo zdarzeń, ale również ich wagę (np. znaczenie) (Guiaşu 1971). Trzecim pojęciem kluczowym, ujętym w przeglądzie teoretycznym, jest algorytmiczne generowanie fasad. Autor zwraca uwagę na gwałtowny rozwój zainteresowania tym zagadnieniem w ostatnich dwóch dekadach. Niemniej jednak, liczne publikacje skupiają się przede wszystkim na zagadnieniu optymalizacji fasad w konkretnym kontekście (nasłonecznienie, efektywność energetyczna itp.). Nie odnaleziono publikacji skupiających się na wykorzystaniu narzędzi algorytmicznego generowania fasad w kontekście ilościowego kodowania estetyki.

Jak już wspomniano, w Publikacji VI posłużono się rozwinięciem metodologii opisanej w Publikacji V. Materiał badawczy stanowiło 343 kompozycje prostokątów, symbolizujących otwory okienne czy też panele elewacyjne. 245 kompozycji stanowiło materiał badawczy z Publikacji V. 98 kompozycji zostało stworzonych jako nowe, lecz nadal bazujące na 49 zdjęciach realizacji architektonicznych, nominowanych do nagrody im. Miesa van der Rohe, edycja 2024 w kategorii mieszkalnictwo zbiorowe. Następnie, przy pomocy skryptu komputerowego, dla każdej z kompozycji dokonano wyliczenia 7 wskaźników matematycznych, bazujących na ważonej entropii Shannona. Względem Publikacji V dokonano także zmiany w odniesieniu do metodologii analiz statystycznych, które w Publikacji VI, w opinii autora, są czulsze na zmiany bazowego współczynnika regularności wizualnej jako zmiennej kategorialnej, a nie interwałowej.

Analiza statystyczna wyników badania pozwoliła na wyabstrahowanie wskaźnika SVE_{DAS}, który koreluje z regularnością wizualną kompozycji, stanowiących materiał badawczy, w ponad 96%. Ponadto, ww. wskaźnik w 96% prawidłowo porządkuje pary kompozycji pod kątem regularności wizualnej. Oryginalny wskaźnik $H_{centerdist}$, opisywany na łamach Publikacji V, uzyskał w badaniu opisanym w Publikacji VI korelację na poziomie blisko 93% a w przypadku ponad 88% par prawidłowo porządkował je pod kątem regularności. W sensie liczbowym prezentowana poprawa czułości nowego wskaźnika SVE_{DAS} względem oryginalnego $H_{centerdist}$ jest czysto ewolucyjna, nie zaś rewolucyjna. Niemniej jednak, wskaźnik SVE_{DAS} prezentuje znacznie większą czułość w przypadku bardzo subtelnych zmian kompozycyjnych, na co wskaźnik $H_{centerdist}$ w ogóle nie był czuły – wskazywano na te ograniczenia już w ramach Publikacji V.

Dodatkowym, aplikacyjnym, efektem Publikacji VI było stworzenie narzędzia cyfrowego, które pozwala wygenerować wzory kompozycyjne elementów elewacji (np. okien) o zadanych parametrach architektonicznych (ilość kondygnacji, wysokość kondygnacji, długość elewacji, wymiary elementów kompozycyjnych), o konkretnym typie kompozycji (zgodnie z typologią kompozycji opisywaną w Publikacji II), a także o konkretnej wartości regularności wizualnej (określonej współczynnikiem SVE_{DAS}). Narzędzie wraz z kodem źródłowym udostępniono poprzez platformę Most Wiedzy na zasadach open-source. Publikacja VI domyka zatem cały cykl badawczy, przechodząc od diagnozy i typologii, przez percepcję i preferencje, aż po formalne wskaźniki i ich praktyczną implementację w postaci narzędzi generatywnych, mogących realnie wspierać proces projektowania fasad.

Podobnie jak w Publikacji V, badanie opiera się na uproszczonym modelu fasady i ograniczone jest do kompozycji prostokątnych, co należy traktować jako świadome zawężenie zakresu na rzecz klarowności metodologicznej. Zastosowanie SVE_{DAS} jako funkcji celu w narzędziu generatywnym wymaga dalszych testów w zróżnicowanych kontekstach projektowych, jednak już na obecnym etapie wskazuje na realny potencjał wykorzystania ilościowych miar regularności w praktyce projektowania architektonicznego.

4. PUBLIKACJE WCHODZĄCE W SKŁAD ROZPRAWY

4.1 PUBLIKACJA I

technical transactions

No. 2022/009

architecture and urban planning

sciendo

Features of irregularity in examples of Polish multi-family architecture constructed in 2011–2021 and nominated for the Mies van der Rohe award

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Technical Editor: Aleksandra Urzędowska, Cracow University of Technology Press
Language Verification: Timothy Churcher, Merlin Language Services
Typesetting: Anna Pawlik, Cracow University of Technology Press

Received: December 21, 2021
Accepted: June 20, 2022

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing interests: The authors have declared that no competing interests exist.

Citation: Malewczyk, M., Czyż, P. (2022). Features of irregularity in examples of Polish multi-family architecture constructed in 2011–2021 and nominated for the Mies van der Rohe award. *Technical Transactions: e2022009*. https://doi.org/10.37705/TechTrans/e2022009

Abstract

This article is devoted to the analysis of contemporary Polish multi-family architecture in the context of aesthetic irregularity. The research was limited to constructions from 2011–2021 and nominated for the Mies van der Rohe award as the objects with the greatest potential impact on shaping further trends. In their research, the authors focused on searching for the features of irregularities, which, in their opinion, have become a distinguishing feature of contemporary architectural aesthetics. The analyses in this study refer to three planes of the aesthetic dimension of architecture, namely the form, facade composition and material.

Keywords: Mies van der Rohe, multi-family architecture, irregularity, aesthetics, contemporary architecture, Polish architecture

1. Introduction

The aim of this study is to analyse Polish multi-family housing projects which have been nominated for the European Union Prize for Contemporary Architecture (Mies van der Rohe Award) and were completed between 2011 and 2021. The research focuses on the search for features of aesthetic irregularity, primarily in the context of form, composition and facade material.

The study group is limited to housing developments from the last decade for two reasons. First of all, modern multi-family housing architecture is facing a serious challenge, which is the huge demand for housing resulting from generational changes and the growing economic level of young Poles. Such a high demand means the construction of thousands of new housing facilities that will change the face of cities for many years to come. Secondly, the facilities completed in 2011–2021 are contemporary buildings which are both the result of contemporary thinking about architecture and have the strongest impact on other, newly designed projects. Moreover, the fact that the group of reference objects was narrowed down to those nominated for the Mies van der Rohe Award means a reduction to the group of the most significant objects and the strongest determinants of trends in shaping the aesthetics of contemporary Polish multi-family housing.

The key issue for the research is irregularity in the context of the aesthetics of architecture. Irregularity is a natural consequence of rejecting regularity, which, according to the dictionary definition, refers to elements compliant with undefined rules, but also (with regard to visual aspects) having a shape similar to basic geometric figures and proportionality or symmetry (Sobol, 2007). Naturally, the problem of regularity can also be considered as a kind of scale where, on the one hand, there are ideal structures, and on the other there are completely chaotic structures (Rubinowicz, 2000). With regard to architecture, the pursuit of ideal structures was already very clear in antiquity and determined this field of art for centuries (Rubinowicz, 2000). The above state resulted from the classic relationship between art and beauty and the Great Theory of Beauty (Tatarkiewicz, 1972), based on principles such as harmony and symmetry. Nowadays, however, there is a clear tendency towards the other end of the regularity scale. According to the authors, it is irregularity that has become a distinguishing and characteristic feature of contemporary architecture.

The results of the analyses are to help structure knowledge about the aesthetics of contemporary Polish multi-family residential architecture. Moreover, it is assumed that they will enable the definition of directions for further research on the above subject. The expected long-term effect is the broadening of knowledge about the methods of designing and shaping the visual layer of multi-family housing, and at the same time, increasing the awareness of the designers themselves on this subject. Equally important is also the possibility of improving the education of architecture students.

2. Irregularity

Irregularity can be considered in many ways. First of all, it can be deliberate, which is the result of an intended action, or accidental, which is the result of, for example, mistakes. Random irregularity was present in art as early as Hellenistic times (Politt, 1986) (Hellenistic Baroque) and was also associated with ugliness. This aesthetic category was also present in medieval or baroque art but had no value in itself. Only in the nineteenth century, ugliness, breaking the traditional canons of beauty, appeared in realism and naturalism. And as an inherent aesthetic value, it became an element of twentieth-century avant-garde and trends such as neoclassicism or turpism (Stolnitz, 1950). However, deliberate irregularity was an even rarer phenomenon in historical art and architecture, it can be seen rather as an element of nature in romantic gardens or in elements of Art Nouveau. Strictly geometric irregularity began to appear only with the development of trends such as expressionism or cubism, but in architecture, it was only the modernists who began to break the principles of symmetry and destroy the ancient, axial compositions of the facades. Nowadays, irregularity should also be considered in terms of novelty (Czyż, 2013) as a counterpoint to the traditional way of shaping aesthetics.

Irregularity, however, does not only refer to aesthetic issues, and it does not arise only from the theory of art and the relationship between art and beauty. This concept is closely related to the broadly understood philosophy. If we consider regularity as submission, irregularity is the absence of this submission. Regularity was thus the main feature of the creativity of traditional and industrial societies, that is, clearly structured societies characterised by a collectivist approach. Irregularity, on the other hand, appeared as a sign of the negation of earlier structures, which took place at the beginning of the twentieth century, i.e. at the time when the post-industrial society arose. Today, irregularity can therefore be treated as the essence of postmodern philosophy, which emphasizes the importance of individualism and rejects conservatism in favour of liberalism.

Irregularity should also be considered in the context of the Japanese philosophy of wabi-sabi, which originates from Asian countries, which are also outside the strong influence of European cultural circles. Although the word wabi originally meant "poverty" and sabi can be translated as a state of deterioration over time, cultural changes and the influence of Buddhism have made these words positive. The philosophy of wabi-sabi means, first of all, the acceptance of transience and imperfections (Koren, 1994), but it also refers to modesty, accepting one's own weaknesses and limitations as well as the love of nature. It is a philosophy of life and it affects all its aspects, including aesthetics. The aesthetics associated with the wabi-sabi philosophy is characterised by an organic, natural imperfection of form, shape and material. It is also minimalist but not ascetic and purist at the same time. It is a response to human needs, while opposing consumerism manifested in splendour. In a sense, aesthetic similarities can be found in the architecture of critical regionalism (Carlson-Reddig, 2019), which, however, is not in itself a new theoretical model but a reinterpretation of local traditions. Therefore, this trend is strongly related to craftsmanship and is characterized by the use of local, natural materials. Irregularity is therefore an element of critical regionalism as an additive, not an essence. Ideologically, the wabi-sabi philosophy is more closely related to the views presented by Steven Harris in the book "Architecture of Everyday" (Harris, 1998).

In the light of the above considerations, irregularity should be treated as a complex and strongly culturally conditioned issue. Moreover, it is understood differently depending on the region. Nevertheless, the irregularity appears to have increasing value. On the one hand, it introduces diversity and novelty, which are in line with the postmodern spirit of consumerism, and on the other hand, it can be an expression of an aesthetic rebellion against the above. Undoubtedly, due to its strong connotations with art, aesthetics, the concept of beauty and philosophy, irregularity also affects the theory of architecture and the creativity of designers.

3. Method

In the opinion of the authors, it can be presumed that irregularity is a kind of sign of the times. It is a feature that determines contemporary aesthetics. In order to verify the thesis, an analysis of architectural examples was performed in order to look for irregularities. The analysis concerns three planes of architectural aesthetics – form, facade composition and material. The research was limited to seven multi-family housing projects built in Poland in 2011–2021 and nominated for the Mies van der Rohe Award.

4. Research

4.1. Nowe Żerniki

The Nowe Żerniki estate, also known as WUWA2, is a collective project, the aim of which was to create a new, model housing estate, constituting an alternative to typical Polish housing investments with low functional and aesthetic value (Idea, 2016). It is a project involving the authorities of the city of Wrocław, the District Chamber of Architects of the Republic of Poland and the Association of Polish Architects, as well as over forty architectural studios (Idea, 2016). The estate was nominated for the Mies van der Rohe Award – 2019 and 2022 editions. Although the entire project is the result of cooperation of a large group of designers, it has a coherent, neo-modernist character.

Particular attention should be paid to the Atmosfera estate (Fig. 1), which is part of the Nowe Żerniki complex. The buildings have a minimalist form of cuboids in which loggias and window openings have been cut out (also

Fig. 1. Atmosfera Estate (source: https://serwer1456053.home.pl/autoinstalator/wordpress/portfolio_page/osiedle-atmosfera-na-nowych-zernikach)

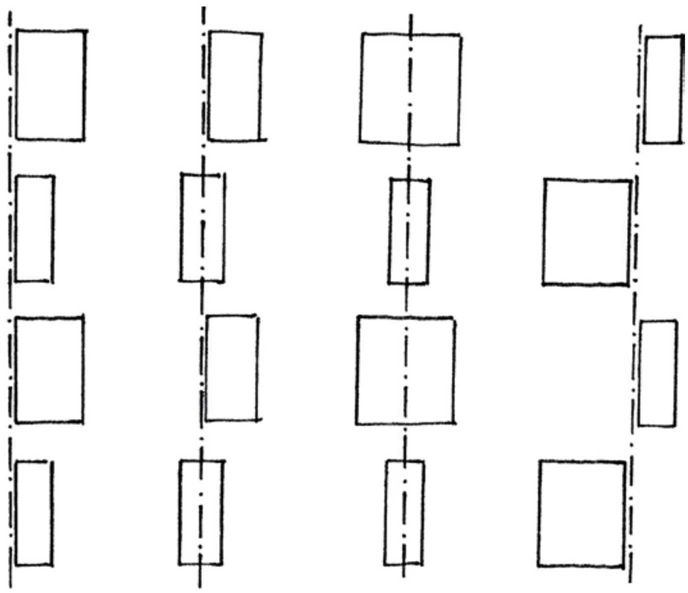

Fig. 2. Composition schemes of the Atmosfera estate facades (own elaboration)

https://doi.org/10.37705/TechTrans/e2022009

cuboidal). The subtraction of smaller cuboids from the main one is emphasised by the material – graphite woodwork, graphite window recesses and wooden loggia recesses strongly contrast with the white face of the main body of the building. However, attention should first be paid to the used compositional treatments, which give irregularities and break down the aesthetic simplicity of these buildings. On the elevations of the Arch_it design, several compositional operations can be observed (Fig. 2). There are compositions based on vertical lines that are tangent to one of the edges of successive compositional elements or the axis of symmetry of these elements. Some of the openings are arranged in accordance with their axis of symmetry, however, subsequent openings have different widths. The alternating occurrence of some openings on subsequent storeys can also be observed. The whole has a minimalist, even purist character, but the play with window openings is a counterpoint and introduces dynamism, which is a characteristic feature of the analysed estate.

4.2. Riverview

A residential development project (Fig. 3), located on the banks of the Motława River in Gdańsk, is an example of multi-family housing with modern aesthetics, which at the same time tries to refer to the historical context of buildings. The design of the APA Wojciechowski team consists of seven buildings, which formally consist of very simple, repeatable cuboids, topped with symmetrical, gable roofs. It should be noted, however, that although the individual elements are synthetic, regular, unitary forms, they have been arranged in an irregular way. Blocks were slightly displaced and differentiated in terms of height. In this way, the juxtaposition of the smaller blocks does not reveal the actual scale of

Fig. 3. Riverview Estate (source: https://architektura.muratorplus.pl/realizacje/osiedle-riverview-w-gdansku_10602.html)

the individual buildings in the estate and at the same time constitutes a spatial reference to the traditional architecture of this part of Gdańsk. The irregular juxtaposition of regular solids makes the complex appear to be formally diverse, although its components are not. The elements that break the regularity of individual solids are the compositions of the facades and the material. The top facades, which are the most exposed, are irregular compositions of window openings with asymmetric divisions (Fig. 4). The window openings themselves rest against two main modules, used alternately. Elements on each of the elevations form two compositional axes marked by the outer edges of the windows. In addition, the irregularity and asymmetry are emphasized by a single, repeatable window on each facade, which has a different (in relation to the main elements) height and an elevated sill. The location of the element itself is asymmetrical but not in line with the main compositional axes of the facades. You should also pay attention to the material from which the facades

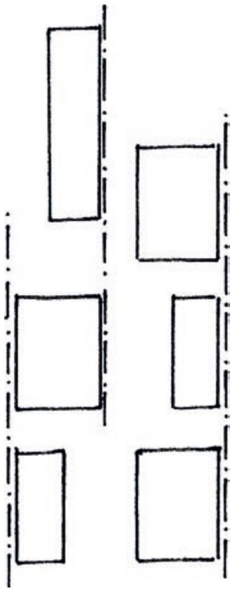

Fig. 4. Composition scheme of the gable facades of the Riverview Estate (own elaboration)

are made. Clinker bricks with uneven colours dynamise very simple, minimalist shapes, adding life to them.

4.3. Nowy Werdon

The "Nowy Werdon" building (Fig. 5) is a response to the need for the revitalisation of mining areas in Silesia. The residential building is a minimalist, rectangular shape covered with a steep, two-slope roof with a symmetrical layout. The regular form is a continuation of the historical urban fabric, while the architecture itself is a contrast in the form of the irregular composition of the facades, emphasised by the material – clinker bricks. The initial compositional system is very simple and is based on a regular axis system. The regularity of the pattern is disturbed by locally introduced holes, with a width clearly bigger than width of the windows, and by moving the elements horizontally (Fig. 6). The facade material completes the composition. The brick laid on the basis of an orthogonal mesh emphasizes the regular character of the block and the varied colour of the clinker breaks this regularity.

Fig. 5. Nowy Werdon building (source: http://www.maleccy.com/pl/projekty/nowy-werdon)

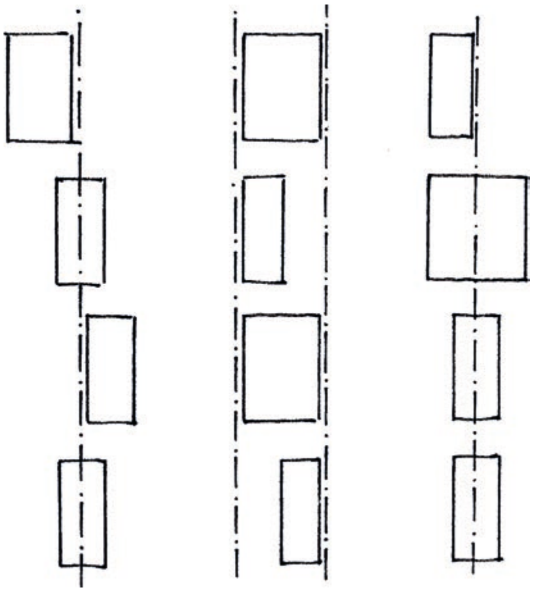

Fig. 6. Nowy Werdon building (own elaboration)

4.4. Nowy Nikiszowiec

Another analysed project is one nominated for the 2022 Mies van der Rohe Award 2022 – this is the Nowy Nikiszowiec estate (Fig. 7) in Katowice. The group of quarter buildings consists of rectangular buildings of regular forms but dynamised by the arrangement of the gable walls located in the corners of the quarter at an angle to the longer facades of the buildings. Such an operation, although partly due to urban planning conditions, formally introduces an element that breaks the geometrical correctness of cuboidal solids. The composition of the facades of the discussed quarter of the buildings is characterised by consistent repetition and regularity. Axially arranged window openings, adapted to the functional arrangement, build aesthetic harmony and peace. An additional breaking element, however, is the facade material. The facades were divided into regular, rectangular fields with the help of vertical and horizontal cutters. The quarters are filled with plaster glistening in the sun with an admixture of quartz and mica, which gives the material both nobility and diversity. The whole is in shades of soft, brick orange, referring to the development of the Nikiszowiec estate, built at the beginning of the twentieth century. However, attention should be paid to subtle colour differences between individual fields, which introduces an element of irregularity. This procedure transforms an extremely decent, almost boring, architecture into a very interesting example of contemporary Polish multi-family housing.

Fig. 7. Nowy Nikiszowiec Estate (source: https://www.designalive.pl/mies-van-der-rohe-award-2022-rekordowa-liczba-nominacji-z-polski)

4.5. Unikato

The “UNIKATO” multi-family residential building (Fig. 8) was designed by the KWK Promes office and nominated for the Mies van der Rohe Award in 2019. A single-block, rectangular form with an extremely regular, even monotonous facade division is broken by a group of balconies. This group also consists of cuboidal elements arranged in a rectangular, spatial pattern; however, a gentle rotation of the balcony layout in relation to the directions of the main body and the uncompromising consequence of this action clearly dynamise the whole. A formal procedure that is essentially simple creates an irregular form out of two regular patterns. The whole is enriched by graphite plaster that covers all facades and balconies. The uneven structure and colour add variety to the building and give the impression that it was built of carbon, which was the inspiration for the designers.

Fig. 8. Unikato building (source: https://www.miesarch.com/work/3955)

4.6. Sprzeczna 4

The Warsaw implementation of the BBGK Architekci project is a contemporary manifesto of prefabrication. This building (Fig. 9) has extremely simple facades made of repeatable, smooth, uniformly coloured

Fig. 9. "Sprzeczna 4" building (source https://www.bryla.pl/bryla/7,85301,22621090,sprzeczna-4-manifest-nowoczesnej-prefabrykacji.html)

https://doi.org/10.37705/TechTrans/e2022009

reinforced concrete elements. This is due to the conditions of the building technology itself, which was supposed to be emphasised by the aesthetics of the architecture itself. However, attention should be paid to the main facade of the building, turned at an angle of 45 degrees. On the one hand, it results from the shape of the plot itself, but on the other hand, it is a deliberate architectural procedure. This shape of the form allowed for the creation of triangular balconies, which, in combination with the perspective and chiaroscuro, constitute an irregular element, dynamising and breaking the monotonous, repetitive character of the building.

4.7. 19 Dzielnica

The 19 Dzielnica estate, located in Warsaw and designed by JEMS Architekci, was nominated for the 2013 Mies van der Rohe Award. The urban complex, ultimately consisting of ten buildings (seven completed), is located on the post-industrial outskirts of the city centre of the capital (Osiedle 19 Dzielnica). Formally, all buildings are minimalist, cuboidal shapes; however, they have very characteristic, irregular facades, which are a special feature of the six buildings built in stages I, II and III. Two buildings constructed in the first stage (Fig. 10) have a regular arrangement of window openings, adjusted to the function and multiplied for the next storeys, the irregularity is an element added only in the next layer of the composition. With the help of dark borders, wood and white plaster, visually separate compositional elements were created, the widths of which are different on different floors. Therefore, despite the real repeatability of the storeys and window openings, the whole thing seems to be dynamic and irregular. The next objects, realised in stage II (Fig. 11), have facades with irregular composition already in the basic layer. It is true that after a more detailed analysis, vertical composition lines are clearly visible; however, the use of window openings of different widths and their arrangement in a vertical array only in relation to one of the side edges builds a strong dynamism. The compositional principles applied here are analogous to those on the facades of the Atmosfera estate in Nowe Żerniki (Fig. 2). In addition, the impression is intensified by the clear separation of individual storeys with white stripes, so that the groups of windows are not read as vertical elements (which breaks the natural principle that Arnheim wrote about (Arnheim, 1978)), but belong to separate, horizontal stripes. However, it is impossible not to notice the clear similarity to the façade of the town hall building in Murcia, designed by Raphael Moneo. The buildings constructed in stage III (Fig. 12) have facades based on a slightly different principle. The elevations are divided into repetitive, square

Fig. 10. 19 District – I stage (source: https://jems.pl/projekty/wybrane-prace/19-dzielnica.html)

fields, which are irregularly filled on subsequent floors with windows with the full width of the module or its half. In some places, the dividing lines between adjacent fields have been filled with a material that contrasts with the main colour of the facade, which visually connects two modules into one. Although the etiology of this composition is slightly different, in fact, its resonance in relation to the composition of the facades of the buildings erected in stage II is very similar. The principle of creating the above-described composition is shown in the diagram (Fig. 13).

Fig. 11. 19 District – II stage (source: https://jems.pl/projekty/wybrane-prace/19-dzielnica.html)

Fig. 12. 19 District – III stage (source: https://jems.pl/projekty/wybrane-prace/19-dzielnica.html)

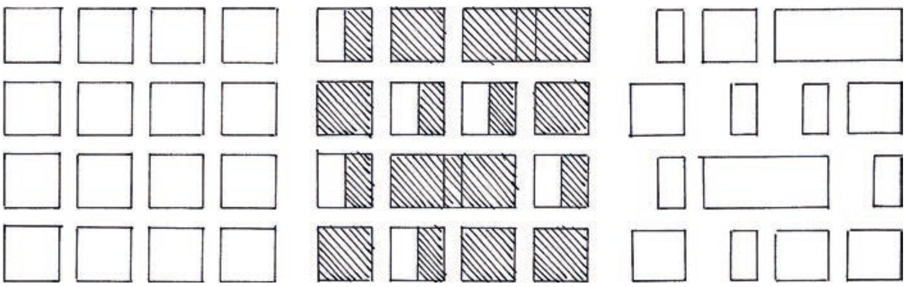

Fig. 13. Composition scheme of the facades of the buildings of the 3rd stage of the 19th District, on the left – the initial composition, in the middle – the optional filling of the quarters, on the right – the final composition (own elaboration)

5. Summary of research

In connection with the above analyses, formal irregularities were found in four cases, which accounts for 57.2% of the researched implementations. Facades with an irregular composition also characterise four out of seven housing estates – 57.2% of the total. The irregular material on the façade has the same number of realisations. It should also be noted that one project (14.4%) has the features of formal irregularity, composition and material, three housing estates (42.8%) have an accumulation of two features of irregularity, and the other three (42.8%) have at least one. The results of the analysis are summarised in Table 1.

Table 1. List of irregularities in relation to the analysed housing developments

Name of project	Designer	Irregularity of form	Irregularity of composition	Irregularity of material
Nowe Żerniki	Projekt zbiorowy		X	
Riverview	APA Wojciechowski	X	X	X
Nowy Werdon	Biuro Projektowe Małeccy		X	X
Nowy Nikiszowiec	22ARCHITEKCI	X		X
Unikato	KWK Promes	X		X
Sprzeczna 4	BBGK	X		
19 Dzielnica	JEMS Architekci		X	

6. Discussion

All the above-mentioned examples prove that irregularity is a phenomenon that is heavily exploited in the field of contemporary Polish residential architecture. This irregularity applies to all three aspects of architectural aesthetics – form, composition and material. Nevertheless, attention should be paid to the manner and scope of the application of this irregularity. Due to the nature of its function, housing construction is still shaped on the basis of cuboidal solids, which are only dynamized by various types of treatments. Within this type of architecture, however, a very strong trend can be noticed related to the irregularity of the facades themselves in terms of their composition and material. Diverse arrangements of window openings and a variety of colours and textures of materials seem to be a way to break the boxiness of modern multi-family buildings. It is also an element that allows for a certain individualisation of, in fact, very similar new development investments. This procedure is of course related to the product approach to residential architecture. The huge number of newly built housing estates forces developers to individualise and distinguish one product from another. Nevertheless, it has a very positive impact on the quality of the architecture itself.

7. Conclusion

The above considerations apply to the analysis of selected, albeit very significant and award-winning objects, which are an inspiration for other architects and designers. In the opinion of the authors, however, quantitative research should be performed to show specific data on the frequency of irregularities in terms of form, composition and material, which will show the real tendency in the context of the entire contemporary Polish housing construction. The introduction of irregularities into architecture in the context of two issues also seems disturbing. Firstly, too much visual diversity is a problem for contemporary cities (Kozlova, 2018) and the irregularity applied to individual architectural objects only increases this level of diversity. Secondly, research conducted among people professionally associated with architecture and other people (Akalin, Yildrim, Wilson, 2009, Safarova, Pirko, Jurik, 2019) proves that the aesthetic judgments of these two groups differ significantly. Therefore, it can be presumed that the objects analysed in this study, although nominated for the prestigious architectural award, are not perceived by average users as visually attractive. This is puzzling as architecture, especially residential architecture, should be

designed with the users in mind. Therefore, research on aesthetic preferences should be carried out, primarily in the context of the problem of irregularities in the group of typical multi-family housing, which is the basic building block of urban tissue.
During the analyses, the authors also noticed clear similarities between the examined objects in terms of shaping the composition of the facades. Therefore, it can be presumed that there are specific compositional types. Thus, research should be conducted on a larger group of reference objects in order to search for characteristic features common between various compositions and, as a result, to define their typology

References

Akalin, A., Yildrim, K., Wilson, Ch. (2009). Architecture and engineering students' evaluations of house facades: Preference, complexity and impressiveness. *Journal of Environmental Psychology*, 29(1).
Arnheim, R. (1978). *The Dynamics of Architectural Form*. Berkeley: University of California Press.
Carlson-Reddig, K. (2019). Re-Reading Critical Regionalism. In *Local Identities Global Challenges, ACSA Fall Conference*, 2011.
Czyż, P. (2013). *Normatywna zawartość architektury po-ponowoczesnej*. PhD Thesis. Gdańsk: Politechnika Gdańska.
Harris, S. (1998). *Architecture of the Everyday*. Princeton: Princeton Architectural Press.
Idea (2016). Retrieved from http://nowezerniki.pl/idea/ (date of access: 2021/05/15).
Koren, L. (1994). *Wabi-Sabi for Artists, Designers, Poets and Philosophers*. Berkeley: Stone Bridge Press.
Kozlova, N. (2018). Architectural organization of facades according to principle of variability: videoecological aspect. *Journal of Architecture and Urbanism*, 42(1).
Osiedle 19 Dzielnica. Retrieved from https://www.19dzielnica.pl/osiedle-19-dzielnica/ (date of access: 2021/05/15).
Politt, J.J. (1986). *Art in the Hellenistic age*. Cambridge: Cambridge University Press.
Rubinowicz P. (2000). *Chaos and Geometric Order in Architecture and Design*.
Safarova, K., Pirko, M., Jurik, V. (2019). Differences between young architects' and non-architects' aesthetic evaluation of buildings. *Frontiers of Architectural Research*, Vol. 8(2).
Sobol, E., Drabik, L. (2007). *Słownik języka Polskiego PWN*. Warszawa: Wydawnictwo Naukowe PWN.
Stolnitz, M. (1950). On Ugliness in Art. *Philosophy and Phenomenological Research*, 11(1): 1–24.
Tatarkiewicz, W. (1972). The Great Theory of Beauty and Its Decline. *The Journal of Aesthetics and Art Criticism*, 31(2): 165–180.

4.2 PUBLIKACJA II

Nexus Network Journal
https://doi.org/10.1007/s00004-022-00614-y

Nexus Network Journal
Architecture and Mathematics

RESEARCH

Composition Patterns of Contemporary Polish Residential Building Facades

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Accepted: 12 May 2022

Abstract

This study aims to define the types of composition patterns of contemporary Polish multi-family building facades. The authors define the compositional patterns to determine their frequency. Analyses carried out on the basis of photos and visualizations of 113 examples of architecture from Poland identified groups of common features of facades. Statistical analyses of these features resulted in six types of compositions. Clear differences were noticed in relation to features, such as the repeatability of compositional elements and the method of building a vertical compositional axis. Variations were observed in the frequency and extent of application of specific types of compositions. The results of this study can be a starting point for the development of generative algorithms supporting the process of designing facades. Specifying the types will allow for further exploration of the theme, both in terms of the use of specific compositional measures and in terms of their perception.

Keywords Multi-family housing · Residential architecture · Design analysis · Design theory · Patterns · Proportion

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Published online: 13 June 2022

Birkhäuser

Introduction

The aim of this study is to define the types of compositional patterns used on the facades of contemporary Polish residential buildings. Patterns, understood as models of facade compositions were designed, i.e. the arrangement of architectural elements (such as windows, panels, or balconies) on the elevation, were essential for this study. The conducted research is of a cross-sectional nature and its task is to describe the current and general trends relating to all kinds of multi-family housing facilities.

It is important to note that residential buildings are the most common type of building in almost every city. This is also true in the Polish cities today due to the huge demand. Taking that into account, one can see the prevalence of the impact of residential buildings on everyday perception of the city.

Therefore, the widest possible research material was collected without subjecting it to any selection. A total of 113 photographs (Fig. 1) and visualizations of the facades of multi-family buildings used from 2018 to 2021 and those under construction when the research was gathered were collected. The data from the statistical analysis of the research material made it possible to discover groups of compositions with common features and to determine the typology (understood as distinguishing types) of facade composition patterns. Although the proposed research method refers only to examples of architecture from Poland, it is a universal method. Its application to other parts of the world does not require any changes.

In the opinion of the authors, the composition of the facades of architectural objects is a topic that has become marginal from a theoretical point of view. Historically, the composition of the facade was an element guided with strict rules. An example of such rules can be mathematically defined according to the ways ancient Greek temples were designed (Coulton 1975). The method of shaping the composition of the facade was also strictly defined in later architectural treatises (Alberti 1986) and stencils (Boros 2017; Zawadzka 2017). The current scientific studies mainly refer to general laws of perception (Arnheim 1977; Shemesh et al. 2019), symmetry of the facade (Park 2018) or the divine proportion (Thapa and Thapa 2018). There are also studies focusing on the analysis of the facade composition of specific architectural objects, both historical (Krier 1988; Zawadzka 2017) and contemporary (Eardley 2022). The conclusions drawn from them, however, are general in nature and do not constitute specific guidelines for designers. The topic of designing facades is also explored in terms of designing zero-energy buildings (Thalfeldt et al. 2013), generative architecture, (Cudzik and Radziszewski 2018) or daylight quality (Lim et al. 2012). These types of studies naturally have an impact on the aesthetics of the facades, but in the authors opinion, they are mainly a source of inspiration.

There are also studies and methods allowing a parametric assessment of the aesthetics of architectural designs. One example is the Birkoff method (Davis 1936), which was further refined by Enysenck (1941). This method assumes that the aesthetic value of an object depends on parameters, such as the complexity and

Fig. 1 Randomly selected photos from the research material for the study. Image: otodom.pl

order of the facade (Meddahi and Boussora 2021). However, these parameters can be determined post factum, after designing the facade. No contemporary studies constituting a set of specific guidelines for the design of the facade composition have been found. This may be related to the prevailing philosophical trends and the individualistic approach of designers (Inglehart and Oyserman 2004).

Despite the unique approach of architects to shape architectural objects and the absence of general, theoretically constituted design guidelines, the authors believe there is often a clear similarity linking some architectural objects. These similarities are particularly clear in relation to residential, multi-family buildings, which means that there are features that connect the aesthetics of these buildings. There may be several reasons for those similarities.

Residential architecture is subject to many limitations. Since this type of construction is primarily intended to meet the housing needs of users most often unknown at the design stage, it should be largely standardized. Standardization of multi-family housing at the functional level is the result of, for example, the principles of ergonomics described in different studies (Neufert 2012). Standardization as well as functional requirements also necessitate permanent architectural elements, such as windows or balconies. Apart from repeatability, multi-family architecture often uses simple, cuboidal forms. Multi-family housing is also an economically conditioned architectural sector. The abovementioned conditions are reflected, for example, in the renewed interest in the prefabrication (Boafo et al. 2016), which also results in award-winning residential projects, such as the Sprzeczna 4 building, designed by BBGK Architekci.

The limitations described in the above naturally translate into the functional layout and the aesthetic layer of multi-family housing, which cannot be so freely shaped. Globalization, contemporary sources of inspiration for architects, and the conditions to which multi-family housing are subjected certainly favor the typification of the aesthetics of the architecture of these buildings, as well as the potential compositional patterns of their facades. The above factors also allow us to assume that the purpose of the study described in this manuscript can be achieved.

Describing the guidelines and laws that determine the composition of the facade of a building is not tantamount to imposing a specific aesthetic or limiting creative freedom. Familiarity with these laws can positively affect both the work of architects and their creativity, while attempting to define typologies, which dates back to the Age of Enlightenment and constitutes an important argument in architectural discourse (Güney 2007).

Firstly, after defining specific compositional patterns, it will not be necessary to design the facade composition solely on the basis of the designer's intuition; rather, it will be possible to use predefined patterns. This type of approach to architecture was previously proposed by Alexander (1977). The defined patterns can be further explored and potentially new ones can be created. For similar reasons, an attempt to define a typology of patterns was made in the past, for example, in relation to functional systems in multi-family housing (Xiao 2021).

Secondly, isolating the composition as a component of an architectural object may be a starting point for further research based on the perception of these compositional patterns. In the authors' opinion, the key to the parametric assessment of aesthetic judgments is the isolation of the elements that make up an architectural object. In such a situation, it is possible to learn the opinions of potential users not in relation to specific, already designed buildings, but in relation to the components on the basis of which it will be possible to create architecture. Determining aesthetic preferences for specific types of compositions can, therefore, help to achieve specific, final visual effects in line with the expectations of architecture users. It should be mentioned that the aesthetic judgments of architects as a social group, to a large extent, do not coincide with the judgments made by people not professionally related to designing architecture (Šafárová et al. 2019). The situation described above may, therefore, result in architecture that is not suited to the needs of its potential users.

Parametric evaluation includes such aspects of the composition as its complexity or degree of regularity. Combined with the appropriate nomenclature of shaping local law, it is possible to define the permissible types of facade compositions in a given area. This may help to build spatial order and visual coherence of building complexes, or, to the contrary, help to break the aesthetic monotony. Describing laws that determine specific compositional types opens the way for further studies on creating algorithms that generate this type of composition. In such a situation, the automatic generation of architecture may go beyond the effects of machine learning based on uploaded architecture examples, as contemporary GAN algorithms do (Newton 2019). The algorithm will be able to build architecture from elements, just like an architect does.

This research strictly relates to multi-family housing in Poland. The reason for limiting the research to this region is the problematic situation in which Polish multi-family housing is located (Surówka 2018). Poland has a large housing deficit, despite the number of newly built apartments. It is estimated that the deficit at the end of 2019 was 641,000 apartments. At the same time, the Central Statistical Office report indicates that approximately 1.5 million apartments are in poor condition (Ministerstwo 2020). This has created a huge demand on the real estate market, which has generated a large amount of residential investments, including multi-family units. It should be noted, however, that in Poland the quality of newly built multi-family buildings is highly controversial both among architects and the general public (Wojtkun 2021). The problem of spatial order is also very concerning and the subject of wide debate (Majewska et al. 2020; Kowalewski et al. 2018). Therefore, the authors believe that every effort should be made to solve these problems and broaden the knowledge of design aimed at meeting the needs of users.

Defining the types of facade composition and, in the longer term, examining the public's opinion on abstract composition patterns may contribute to improving the aesthetic quality of future multi-family buildings that are better suited to the tenants.

Research

The aim of this study is to define the types of composition patterns for the facades of contemporary Polish multi-family residential buildings. The key to the study is the Hypothesis 1 indicating that there are clear and common features that link the various facade compositions into groups (types). It is a necessary condition to define the typology of these compositions, i.e., to define the types of compositional patterns used and how they are designed (Research Question 1). It is also important how often they are used (Research Question 2).

The study was conducted on the basis of 113 photographs and visualizations presenting the facades of multi-family residential buildings. The buildings come from all over Poland from 2018 to 2021. Some of them were under construction at the time of the study. The research material comes from one of the most popular online real estate sales websites in Poland (Zielinski 2019). Photographs and visualizations consist of attachments to all apartment sale offers available on 4-12 March 2021 on the above mentioned portal. The material has not been subjected to any preliminary selection; moreover, the real estate portal has been deliberately chosen as the source rather than a magazine or portal related to architecture. The media devoted to architecture evaluates the objects and presents only selected examples. The aim of the study is to identify all types of compositions currently used without evaluating them.

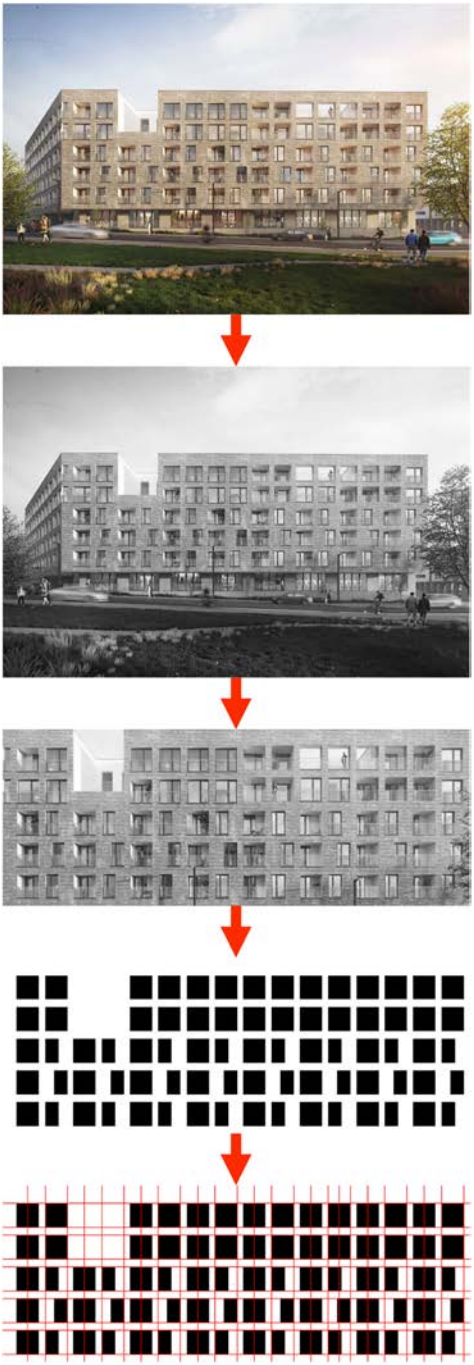
For purposes of the study, the facades of the analyzed objects were reduced to two-dimensional diagrams showing the shape and location of architectural elements (i.e., compositional elements) on the facade. The research material was initially digitally processed in the Affinity Photo program, where the color profile of the files was converted to black and white so that the color would not affect the perception of images. The next step, also with the help of Affinity Photo, was to strip the photos and visualization of perspective distortion. The graphic material prepared in this way was imported into AutoCAD, where the compositional elements were outlined.

In accordance with the theory of multi-layer composition of facades (Tayyebi and Demir 2019) and referring to the methodology of other studies (Meddahi and Boussora 2021), separate diagrams were created for all groups of elements found on a specific facade. Separate diagrams apply to window openings, facade panels, and balconies. Ultimately, 158 diagrams showing the composition of architectural elements on the facade were generated. The diagrams do not show the boundaries of the facade, as the composition itself is the key element for this study. Thus, the schemes show black compositional elements on a white background. Since all marked compositional elements are rectangular with vertical or horizontal edges, vertical and horizontal composition lines have been additionally drawn in the diagrams, tangent to the edges of the compositional elements. The vertical axis of symmetry of each of the individual compositional elements were also marked. Processing of an exemplary photograph is presented in Fig. 2.

The resulting composition diagrams were subjected to parametric descriptive evaluation. Three aspects are crucial for determining the parameters for the evaluation.

Firstly, as previously mentioned, all compositional elements on 158 generated diagrams are rectangular. Secondly, due to the functional requirements of multi-family housing, these facilities most often consist of horizontal stories arranged one above the other. The stories, on the other hand, usually have equal height and repeatable functional arrangements. As a result, compositional elements, most of which are window openings (71.5% of diagrams refer to the composition of window openings), are most often arranged in horizontal rows and vertical columns. Thirdly, the key to the research is the definition of the general rules determining the composition in isolation from the shape and proportions of the facade itself.

Fig. 2 Stages of processing an exemplary photograph that is part of the research material. Image: otodom.pl, authors



Features, such as symmetry of the composition (especially bilateral), can say a lot about the perception of the whole and potentially, about the functional layout of the building. However, in the opinion of the authors, this is not a key feature for abstracting compositional types. It can be assumed that each compositional element is a separate one that influences the perception of the entire facade. It is possible to mirror any composition in the direction of any line (or rotate with copy), resulting in a symmetrical composition. Each facade can also be divided into parts and composed according to different rules. Therefore, the relation between individual compositional elements are important, without regard to the facades and the compositional elements themselves.

It was decided to describe the compositions in relation to the horizontal and vertical dimensions of individual compositional elements and the distance between individual elements, measured vertically and horizontally. Due to the limited perceptual abilities of a human being, we were not able to define a specific number of pattern elements, if they exceeded three or four (Starkey and Cooper 1995) (known as ”subitizing”). Humans also have a limited ability to track items (Alvarez and Franconeri 2007). It is, therefore, impossible for the recipient of architecture to precisely define the dimensions and relationships between compositional elements. The analyzed compositions have from a dozen to several dozen elements, so the perception of this type of facade can only be general. However, it is certainly possible to determine whether the dimensions of all elements or the distances between elements are the same or different (Katkov et al. 2015).

An important aspect of evaluation is the relationship between compositional elements and theoretical composition lines (compositional grid). Due to the natural perception of the building as a vertical object (Arnheim 1977), it was decided to separately describe the contact of the compositional elements with the compositional grid in relation to the lower and upper edges of the elements. The authors believe, however, it is not important whether the compositional elements are tangent to the vertical compositional lines with the right or left edge. Moreover, since it was noticed that the compositional elements are arranged in horizontal rows or vertical columns, it was decided to analyze whether the

Table 1 List of variables for the description of the composition

Feature	Variable 1	Variable 2	Variable 3
The width of the compositional elements	Equal	Unequal	–
The height of the compositional elements	Equal	Unequal	–
Horizontal distances between the elements	Constant	Various	–
Vertical distances between elements	Constant	Various	–
Level of top horizontal edges	Even	Uneven	–
Level of bottom horizontal edges	Even	Uneven	–
Repeatability of columns	Yes	No	Every second
Tangency of elements to the compositional lines	Yes	No	–

arrangement of the compositional elements in the rows or columns is repeatable. The list of nine features with possible variables is presented in Table 1.

An exemplary composition, shown in Fig. 2, is described as follows:

(a) The width of the compositional elements is unequal; compositional elements have different widths.
(b) The height of the compositional elements is equal; all compositional elements have the same height.
(c) Horizontal distances between the elements are varied; horizontal distances between elements vary.
(d) Vertical distances between elements are constant; vertical distances between all elements are equal.
(e) The level of top horizontal edges is even; the levels of the top horizontal edges of the individual composition elements in the following lines are equal and form one clear, horizontal composition line.
(f) The level of bottom horizontal edges is even; the levels of bottom horizontal edges of individual compositional elements in the following lines are equal and form one clear, horizontal line.
(h) Repeatability of columns does not exist; the arrangement of compositional elements in individual columns is not repeatable.
(i) Tangency of elements to the compositional lines does exist; the existence of vertical composition lines was found, constituting a grid for compositional elements, tangent to these lines or arranged so that the axis of symmetry of a given element coincides with the composition line.

Table 2 Observed combinations of composition features

	a)	b)	c)	d)	e)	f)	g)	h)	i)
1	Equal	Equal	Constant	Constant	Even	Even	Yes	Yes	Yes
2	Unequal	Unequal	Various	Various	Uneven	Uneven	No	No	No
3	Unequal	Equal	Various	Contsant	Even	Even	Yes	No	Yes
4	Unequal	Unequal	Various	Contsant	Uneven	Uneven	Yes	No	Yes
5	Unequal	Equal	Various	Contsant	Even	Even	No	No	Yes
6	Unequal	Unequal	Various	Contsant	Uneven	Uneven	No	No	Yes
7	Unequal	Equal	Various	Contsant	Even	Even	Every second	No	Yes
8	Equal	Equal	Constant	Constant	Even	Even	Every second	Yes	Yes

a) width of the elements, b) height of the elements, c) horizontal distances, d) vertical distances, e) level of top horizontal edges, f) level of bottom horizontal edges, g) repeatability of lines, h) repeatability of columns, i) composition lines

Results

Hypothesis no. 1

Hypothesis 1 assumes that clear common features exist between the compositions of the facades of contemporary multi-family residential buildings in Poland. In order to verify this hypothesis, 158 composition diagrams were analyzed and described parametrically using the variables (Table 1) specified previously. The analysis of the list of features of all 158 composition schemes made it possible to distinguish eight features, which are presented in Table 2. Such a limited number of combinations indicates the possibility of defining groups of facades with clear common features. Hypothesis 1 was confirmed, and the abstraction of the groups of common features linking the compositions of the facades provided the basis for answering subsequent research questions.

Research Question 1: What types of compositions are present on the facades of contemporary multi-family residential buildings in Poland?

In order to answer Research Question 1, a re-analysis of the research material was carried out. Compositions were divided into eight groups, in accordance with eight combinations of features demonstrated while Hypothesis 1 was under verification (Table 2). During the re-analysis it was noticed that the compositions described by Features 3 and 4 (Fig. 3) are visually very similar to each other. The differences in these refer to the variables describing the vertical dimensions of compositional elements and the vertical location of these elements in relation to other elements (height of the elements, level of horizontal top edges, level of horizontal bottom edges). Perceptually, the similarity with regard to the compositions described by Features 3 and 4 result from strongly marked verticals, formed by columns composed of repetitive compositional elements and arranged one above the other.

Similar conclusions were drawn during the analysis of the compositions described by the combinations of Features 5 and 6 (Fig. 4). Also in this case,

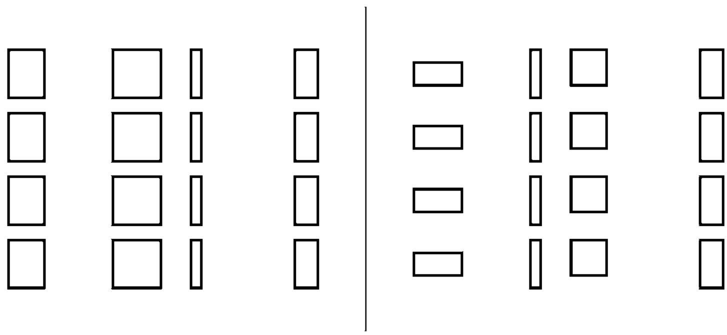


Fig. 3 Exemplary compositions described by the combination of Features 3 (left) and 4 (right). Image: authors

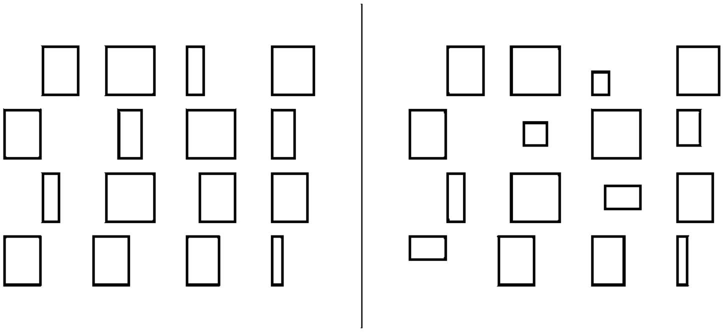


Fig. 4 Exemplary compositions described by the combination of features. 5 (left) and 6 (right). Image: authors

the differences refer to the variables describing the vertical dimensions of compositional elements and the vertical location of these elements in relation to other elements (height of the elements, level of horizontal top edges, and level of horizontal bottom edges). In this case, the key issue determining the perceptual similarity of these compositions consist of theoretical composition lines, marked by the side edges of the compositional elements or by the vertical axes of symmetry of these elements.

Accordingly, six types of compositions were finally distinguished.

Composition Type A

This type of composition is described as Feature combination 1 (Table 2) and is based on identical elements of the same width and height. Horizontal spaces and vertical spaces between elements are both equal. Due to the distances between the elements and their dimensions, such compositions must have a vertical and a horizontal axis of bilateral symmetry. This type of composition can also be characterized with translation symmetry along a vertical and horizontal axis and

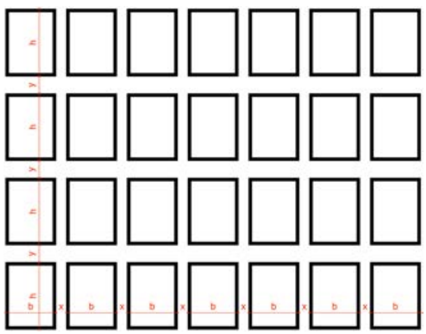


Fig. 5 Sample A composition. Image: authors

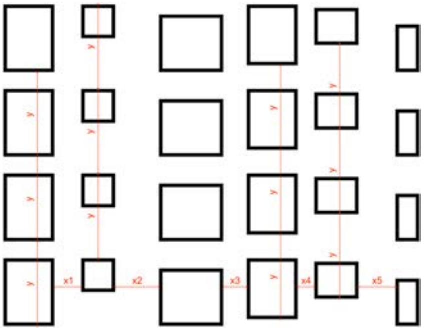


Fig. 6 Sample B composition. Image: authors

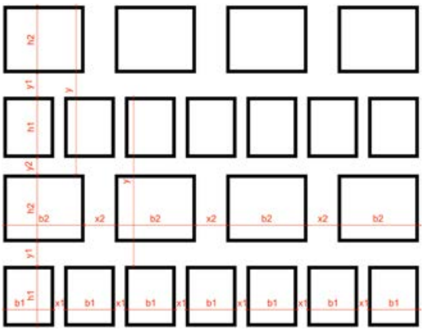


Fig. 7 Sample C composition. Image: authors

also with reflective symmetry along multiple reflection vertical and horizontal axes. The vertical and horizontal spacing values may be different. An example of a Type A composition is shown in Fig. 5.

Composition Type B

This composition is a combination of Features 3 and 4 (Table 2). It is characterized by vertical repeatability but no horizontal repeatability. The key aspect is the different horizontal spacing between the individual compositional elements and translation symmetry along the vertical axis. Compositional elements may have different or repeatable dimensions in both width and height. The elements are arranged in a horizontal row, which is then multiplied vertically. The distances between successive rows are constant. Such compositions are characterized by clearly marked composition verticals. In each piece, there are the same elements, placed one above the other. In other words, this kind of compositions can be reproduced by arranging different vertical columns one next to another, so columns are constructed with identical compositional elements one above the other. The horizontal distances between the risers may vary. An example of a Type B composition is shown in Fig. 6.

Composition Type C

This type of composition is described by the combination of Features 8 (Table 2). A composition of Type C is a mixture of two compositions of Type A. Rows (horizontal rows of compositional elements) of Types A1 and A2 (as two different parametric variations about Type A composition) are arranged vertically and alternately. The vertical distances between all lines are equal. Due to the arrangement of the compositional elements in the lines, these can be characterized as bilateral symmetry with a vertical axis of symmetry as well as with translation symmetry along vertical and horizontal axes. An example of a Type C composition is shown in Fig. 7.

Composition Type D

This composition is described by the combination of Features 7 (Table 2). D type composition is a mixture of two B type compositions. Rows (horizontal rows of compositional elements) Types B1 and B2 (as two different parametric variations about Type B composition) are arranged vertically and alternately. The vertical distances between all lines are equal, so the key feature is translation symmetry along the vertical axis. This type of composition can also be reproduced by arranging vertical columns of composition elements one next to another. In columns every second element must be the same. The number of elements between the columns must also be the same, but columns may vary as well as distances between them. An example of a D-type composition is shown in Fig. 8.

Composition Type E

This type of composition is described by the combination of Features 5 and 6 (Table 2) and is characterized by the use of different elements at different horizontal intervals and a lack of repeatability between lines. The use of elements of equal height in the rows and equal vertical spacing between elements was observed, although this is not a necessary condition. Composition elements arranged in vertical columns tend to be translated along the horizontal axis

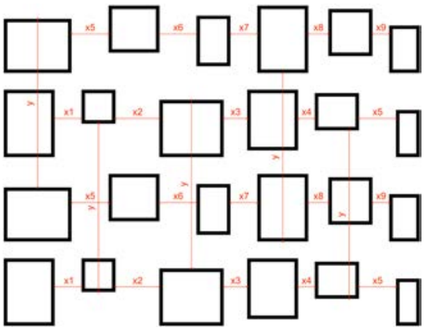


Fig. 8 Sample D composition. Image: authors

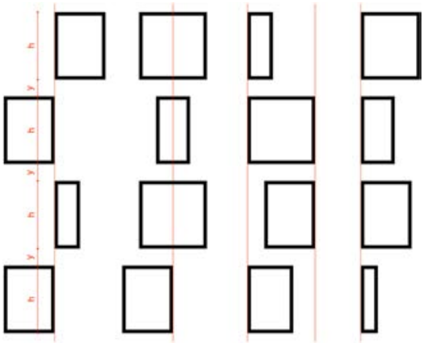


Fig. 9 Sample E composition. Image: authors

and stretched along the same direction. The elements in the following lines are arranged on the basis of theoretical, vertical composition lines, which are usually determined by the lateral, vertical edges of compositional elements or by the symmetry axis of the elements. An example of an E-type composition is shown in Fig. 9.

Composition Type F

This type of composition is described by the combination of Features 2 (Table 2) and is characterized by the use of different elements at different vertical and horizontal intervals. In compositions of this type, the existence of distinct vertical or horizontal composition lines was not observed, linking the individual composition elements together. This type of composition seems completely random and can be generated by translating one rectangle along vertical and horizontal axes while stretching and scaling without any particular rule or order. An example of this type of composition is presented in Fig. 10.

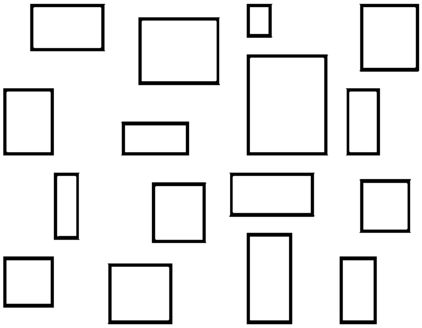


Fig. 10 Sample F composition. Image: authors

Table 3 Descriptive statistics for the frequency of compositional types in the group of analyzed compositional patterns

	Type A	Type B	Type C	Type D	Type E	Type F
Number	19	92	6	13	26	2
Standard deviation	0.3757	0.3907	0.2252	0.3205	0.4228	0.1324
Confidence	0.0693	0.0720	0.0415	0.0591	0.0779	0.0244
Standard error	0.0353	0.0368	0.0212	0.0301	0.0398	0.0125
The minimum value	0.1328	0.7774	0.0319	0.0849	0.1903	0.0052
The average value	0.1681	0.8142	0.0531	0.1150	0.2301	0.0177
The maximum value	0.2035	0.8509	0.0743	0.1452	0.2699	0.0302

Research Question 2: What types of compositions are most often used on the facades of contemporary multi-family residential buildings in Poland?

In order to answer Research Question 2, descriptive statistics were carried out. The results are presented in Table 3. The most common type of composition was Type B, which was noted on 92 compositions out of 158 N (absolute number of items) = 92; M (mean number of items from all items) = 0.8141; SD (standard deviation) = 0.3907). The second most common type of composition was Type E, (N = 25; M = 0.2301; SD = 0.4228). The third most frequent type of composition was Type A, which occurred 19 times (N = 19; M = 0.1681; SD = 0.3757). The next most common type of composition was Type D (N = 13; M = 0.1150; SD = 0.3205). The second rarest composition was Type C, which describes only six compositions (N = 6; M = 0.0531; SD = 0.2252). The least common type of composition was Type F (N = 2; M = 0.0177; SD = 0.1324).

The applied analyses of the research material determined eight groups of features describing the compositions. Ultimately, six types of compositions were distinguished. The most frequently used type was Type B (described in "Composition Type B" of this study), which is related to the functional nature of multi-family housing. The conducted research made it possible to answer all research questions.

Discussion

The aim of this study was to define the typology of compositions used on the facades of Polish multi-family residential buildings. Therefore an analysis of the composition of randomly selected architectural objects was conducted. These analyses led to the distinction of eight combinations of 19 different features in nine dimensions. However, no one particular feature was found among all the compositions tested. Nevertheless, such a clear limitation of the number of combinations allows us to conclude that there are specific, different types of facade compositions and also made it possible to define them.

In the course of further considerations, it was ultimately decided to distinguish six types of compositions. The reason for such a decision was the observed, clear similarity between the compositions described by Features 3 and 4 (Fig. 2) as well as Features 5 and 6 (Fig. 5). The differences between these combinations of features relate to the height of the compositional elements and to the level of the horizontal edges of elements. Buildings, however, are viewed as vertical objects, and the vertical direction takes precedence over the horizontal one (Arnheim 1977). Although many examples of architecture tend to break this rule, buildings observed from the human perspective have a bottom and top part.

The typologies themselves, the description of which is included in "Research Question 1: What types of compositions are present on the facades of contemporary multi-family residential buildings in Poland?" of this article, seems to be a natural consequence of the verticality of buildings. Particular types differ from each other, mainly by the different treatment of vertical lines as the compositional axis, which determine the entire facade. Therefore, the key to defining separate types of compositions was to define horizontal relations between compositional elements and the width of these elements. However, the variation in the height of the elements is of secondary importance. Moreover, uneven, vertical distances between compositional elements are extremely difficult to obtain in the case of multi-family housing, so they are only a marginal phenomenon. This is due to the use of a constant height of the stories, which in themselves usually form horizontal planes, without any offsets. The rows of windows are thus arranged one above the other at a constant, not different, distance.

In response to Research Question 2, statistical analyses were carried out, which show that the most common type of composition is Type B. Setting the window openings on the facade according to the functional distribution and repeating this arrangement on repeatable stories automatically results in the generation of a facade with this type of composition. The above description perfectly fits into the nature of multi-family housing, which is most likely the reason for such frequent use of this type of this composition. The second most frequently used type of composition is Type E. An example of such a composition is the facade of the town hall in Murcia, which is one of the most popular E-type compositions, therefore, it can be presumed that it initiated some kind of fashion. After a publication on the town hall in Polish trade magazines, at the beginning of the 20th century, projects and competition entries, referring to the work of Rafael Moneo, began to appear. This reference to the facade of the town hall is the second stage of the 19 Dzielnica estate, designed by JEMS Architekci. The facades of both implementations have clearly defined, horizontal inter-story stripes, which form a basis for vertical, irregularly spaced elements, between which the window openings have been designed.

The third type of composition in terms of the frequency of occurrence is Type A. This was based on the facades of historic tenement houses (in the Gothic or Renaissance style), and was also present in the architecture of modernism (BGK housing complex, Gdynia). It can be assumed that this type of composition is currently less explored by architects due to the contemporary tendency to depart from such features as symmetry or monumentality. The fourth and fifth type of compositions, in terms of the frequency of occurrence, are respectively Types D and C. Facades based on Type D resemble the compositions of Type E. They are, however, easier to apply, because they are based on two compositions of Type B arranged alternately. Type C compositions, by their nature, resemble a checkerboard pattern and are a derivative of Type A compositions. Therefore, it can be assumed that the infrequent use of this type of composition results from the same reasons as in the case of Type A compositions. Type F composition was only observed on the compositional layer of the facade panels. The lack of any repetition and composition rules make designing this type of facade a great challenge. In addition, the lack of repeatability is also tantamount to higher costs of implementing such a facade, which in many cases is disqualifying.

Conclusion

The conducted research made it possible to answer all research questions and confirmed the assumption that a consistent typology of composition could be defined. It is interesting, however, whether the analysis of examples of foreign multi-family projects would also result in such conclusions. It should also be mentioned that defining the existing compositional types is only tantamount to specifying the boundary conditions according to which certain types of compositional formulas should be designed.

This study is a starting point for further research concerning the perception of abstracted patterns, both by architects and non-architects. Only such results in combination with defined compositional patterns can allow for the creation of a valuable study, which could be a set of guidelines for designers. Such a study would certainly be a great help in teaching architecture students and could also be a kind of signpost during the actual design. Admittedly, this could entail the introduction of limitations for designers.

On the other hand, this study consisted in the analysis of objects that were not subject to such limitations, and it was on this basis that the typology of composition was defined. However, there are doubts about the area for abuse created in this way, especially in the context of local plans, which could, for example, prohibit the use of a composition of a given type in a given area. Nevertheless, with caution and awareness, such a tool could improve the aesthetic coherence of urban areas.

In conclusion, this study allowed the authors to abstract six types of compositional patterns used on the facades of contemporary Polish multi-family buildings. The frequency of each type was also determined.

References

Alberti, Leon Battista. 1986. *The Ten Books of Architecture.* New York: Dover Publications.

Alexander, Christopher. 1977. *A Pattern Language: Towns, Buildings, Construction.* London: Oxford University Press.

Alvarez, George A., Steven L. Franconeri. 2007. How many objects can you track? Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision* **7**(13): 14.

Arnheim, Rudolf. 1977. *The Dynamics of Architectural Form.* Berkeley: University of California Press.

Boafo, Fred Edmond, Jin-Hee Kim, Jun-Tae Kim. 2016. Performance of Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways. *Sustainability* **8**(6). https://doi.org/10.3390/su8060558.

Boros, Grzegorz. 2017. *Obowiazek Piekna. Wzorniki i Traktaty Architektoniczne W Zbiorach PAN Biblioteki Gdanskiej.* Gdansk: slowo/obraz terytoria.

Coulton, J. J. 1975. Towards Understanding Greek Temple Design: General Considerations. *The Annual of the British School at Athens* **70**: 59–99.

Cudzik, Jan, Kacper Radziszewski. 2018. Artificial intelligence aided architectural design. In: *Computing for a Better Tomorrow.* Proceedings of the 36th International Conference on Education and Research in Computer Aided Architectural Design in Europe, Łódź, Poland, 19–21 September 2018, eds. Anetta Kępczyńska-Walczak and Sebastian Białkowski, vol. 1, 77–84. eCAADe.

Davis, R. C. 1936. An Evaluation and Test of Birkhoff's Aesthetic Measure Formula. *The Journal of General Psychology* **15**(2): 231–240.

Eardley, Anthony. 2021. 22 City Halls: Photo Essays on Siena, Louisville, Cincinnati & More Recent Examples. Essay Part 3: Murcia, Spain, (1991). https://eardleydesign.com/halls/e3/.

Eysenck, H. J. 1941. The empirical determination of an aesthetic formula. *Psychological Review* **48**(1): 83–92.

Güney, Yasemin Đ. 2007. Type and typology in architectural discourse. *Journal of Balikesir University FBE* **9**: 3–18.

Inglehart, Ronald F., Oyserman, Daphna. 2004. Individualism, Autonomy and Self-Expression: The Human Development Syndrome. In: *Comparing Cultures: Dimensions of Culture in a Comparative Perspective,* eds. Henk Vinken, Joseph Soeters, and Peter Ester, 73–96. Leiden: Brill.

Katkov, Mikhail, Hila Harris, Dov Sagi. 2015. Visual perception of order-disorder transition. Frontiers in Psychology **6**: 734. https://doi.org/10.3389/fpsyg.2015.00734.

Kowalewski, A., Markowski, T., Sleszynski, P. 2018. Studia nad chaosem przestrzennym. Studia KPZK 182. https://journals.pan.pl/skpzk/125268.

Krier, Rob. 1988. *Architectural Composition*. New York: Rizzoli.

Lim, Yaik-Wah, Mohd Zin Kandar, Mohd Hamdan Ahmad, Dilshan Remaz Ossen, Aminatuzuhariah Megat Abdullah. 2012. Building façade design for daylighting quality in typical government office building. *Building and Environment* 57: 194–204. https://doi.org/10.1016/j.buildenv.2012.04.015.

Majewska, Anna, Małgorzata Denis and Wioleta Krupowicz. 2020. Urbanization Chaos of Suburban Small Cities in Poland: 'Tetris Development'. *Land* **9**(11): 461. https://doi.org/10.3390/land9110461.

Meddahi, Kahina, Kenza Boussora. 2021. Aesthetic Measures of Algiers' Colonial Facades. *Nexus Network Journal* 23: 667–688. https://doi.org/10.1007/s00004-021-00546-z.

Neufert, Ernst. 2012. *Architects' Data*, 4th ed. Hoboken: Wiley-Blackwell.

Newton, David. 2019. Generative Deep Learning in Architectural Design. *TAD Technology Architecture + Design* **3**(2), 176–189 (2019). https://doi.org/10.1080/24751448.2019.1640536.

Ministerstwo Rozwoju i Technologii [Ministry of Economic Development and Technology]. 2020. Raport o stanie mieszkalnictwa. Technical report. https://www.gov.pl/web/rozwojtechnologia/raport-o-stanie-mieszkalnictwa.

Park, Jin-Ho. 2018. Subsymmetries for the analysis and design of housing facades. *Nexus Network Journal* **20**(1): 251–266. https://doi.org/10.1007/s00004-017-0358-4.

Šafárová Katarína, Martin Pírko, Vojtěch Juřík, Tomáš Pavlica, Ondřej Németh. 2019. Differences between young architects' and non-architects' aesthetic evaluation of buildings. *Frontiers of Architectural Research* **8**(2): 229–237. https://doi.org/10.1016/j.foar.2019.04.001.

Shemesh, Avishag, Gerry Leisman, Ronen Talmon, Moshe Bar, Yasha (Jacob) Grobman. 2019. The process of space perception: How do we perceive architecture? In: *Movement 2019: Brain, Body and Cognition,* eds. Joav Merrick and Gerry Leisman, 385–386. Nova Medicine and Health.

Starkey, Prentice, Robert G. Cooper. 1995. The development of subitizing in young children. *British Journal of Developmental Psychology* **13**(4): 399–420 (1995)

Surówka, Marcin. 2018. Deficyt mieszkaniowy jako główny problem polskiego mieszkalnictwa [Residential Deficit as a Main Problem of Polish Housing]. *Studia Ekonomiczne* **358**: 232–242.

Tayyebi, Seyed Farhad, Yüksel Demir. 2019. Architectural Composition: A Systematic Method to Define a List of Visual Attributes. *Art and Design Review* **7**(3): 131–144. https://doi.org/10.4236/adr.2019.73012.

Thalfeldt, Martin, Ergo Pikasa, Jarek Kurnitskia, Hendrik Voll. 2013. Facade design principles for nearly zero energy buildings in a cold climate. *Energy and Buildings* 67: 309–321. https://doi.org/10.1016/j.enbuild.2013.08.027.

Thapa, Gyan Bahadur, Rena Thapa. 2018. The relation of golden ratio, mathematics and aesthetics. *Journal of the Institute of Engineering* **14**(1): 188–199. https://doi.org/10.3126/jie.v14i1.20084.

Wojtkun, Grzegorz. 2021. Epidemic determinats in housing. *Przestrzeń i Forma* **47**: 9–28 (2021). https://doi.org/10.21005/pif.2021.47.A-01.

Xiao, Ran. 2021. Comparing and Clustering Residential Layouts Using a Novel Measure of Grating Difference. *Nexus Network Journal* 23(1): 187–208 (2021). https://doi.org/10.1007/s00004-020-00530-z.

Zawadzka, Monika. 2017. *Fasada Wrzeszczanska.* Gdansk: Akademia Sztuk Pieknych w Gdansku.

Zielinski, Przemysław. 2019. Ranking Najpopularniejszych Portali Z Nieruchomościami. https://przemyslawzielinski.pl/2019/09/ranking-najpopularniejszych-portali-z-nieruchomosciami/.

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4.3 PUBLIKACJA III

buildings

Article

Visual Perception of Regularity and the Composition Pattern Type of the Facade

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Abstract: The present study investigates the degree of visual regularity perceived by viewers in architectural compositions, specifically concerning the type of pattern used. The research is grounded in psychological and neuropsychological universal determinants of visual perception, particularly the perception of visual regularity. The study is based on an empirical survey that involved 48 participants who rated various compositions on a Likert scale. The stimuli presented consisted of a typology of compositional patterns of facades of Polish multifamily buildings developed by Malewczyk, Taraszkiewicz, and Czyż in 2022. The survey results were subjected to statistical analyses, which revealed a clear relationship between the type of composition and its perceived regularity. This implies that architects can predict the perceived regularity of a composition based on its type, which is crucial since visual regularity is closely linked to the sense of spatial order and aesthetic value. Both of these aspects are vital for perceiving architecture as a built environment. The study highlights the significance of visual perception in architectural design, particularly how the public perceives composition types.

Keywords: architecture; aesthetics; cognitive evaluation; environmental psychology; visual analysis

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Citation: Malewczyk, M.; Taraszkiewicz, A.; Czyż, P. Visual Perception of Regularity and the Composition Pattern Type of the Facade. *Buildings* **2024**, *14*, 1389. https://doi.org/10.3390/buildings14051389

Academic Editor: Nikos A. Salingaros

Received: 20 February 2024
Revised: 27 April 2024
Accepted: 30 April 2024
Published: 13 May 2024

1. Introduction

Christopher Alexander's Pattern Language theory is one of the most influential theories in architecture. Initially, it consisted of 253 patterns, which provided solutions to design problems in urban planning, building design, and construction. Malewczyk, Taraszkiewicz, and Czyż [1] identified another pattern related to the composition of elements on the facades of multifamily buildings. This pattern includes six different compositions (shown in Figure 1) that describe all possible arrangements of components, such as windows or balconies on the facade of a multifamily building. However, it is essential to understand how the public perceives these compositions. This study focuses on the visual perception of these composition types. By parameterizing the composition types in terms of their perception by potential viewers, this pattern can be applied with the knowledge of how a statistical viewer will perceive an architectural object based on a particular composition type.

Visual beauty is a crucial factor in architectural design. But how does a building's composition relate to its aesthetic appeal? The following subsection, "Beauty and Composition", attempts to answer this question.

1.1. Beauty and Composition

Several seminal works provide essential context and analysis to deepen the understanding of how the arrangement and composition of architectural elements influence aesthetic appreciation, drawing on psychology and the mathematical principles of fractals.

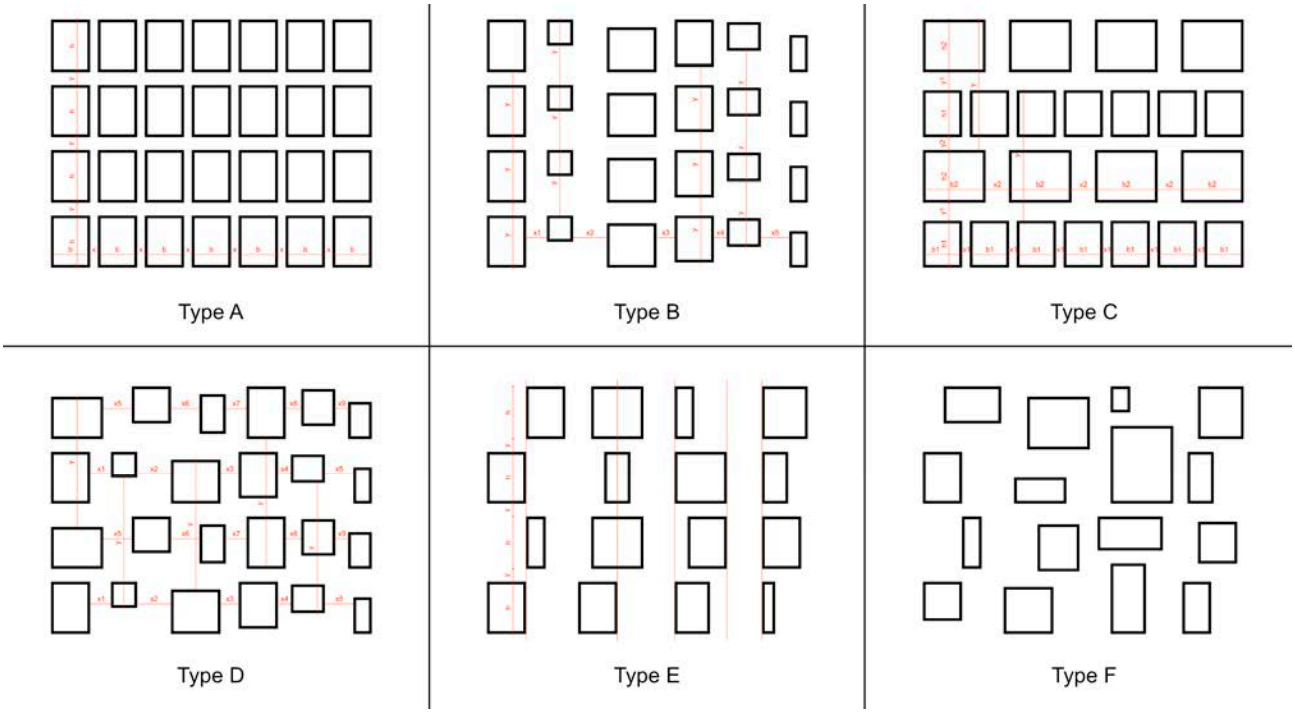

Figure 1. Schemes representing compositional pattern types [1].

Lang's study of the behavioral sciences in environmental design [2] provides valuable insights into the psychological foundations of spatial perception, which can enhance discussions on how architectural composition impacts aesthetics. Arnheim's research on the dynamics of form [3] offers a comprehensive theoretical framework for understanding how architectural shapes and structures affect human aesthetic perception. Bovill [4] introduces fractal geometry as a tool to appreciate the complexity and beauty of architectural designs, providing a scientific approach to understanding the patterns that underlie aesthetic preferences.

Mandelbrot's seminal work on fractals [5] provides the mathematical foundation for discussions on complexity and regularity in architectural patterns, which are essential for understanding the nuances of architectural aesthetics. Ramachandran and Hirstein [6] propose a neurological basis for aesthetic experiences, bridging the gap between the perception of architectural forms and the underlying brain processes. Joye's [7] discourse on biophilic design adds another dimension to architectural aesthetics by highlighting the innate human affinity for nature and natural patterns within built environments.

Zeki [8] explores the neural mechanisms involved in art and aesthetic perception, providing a fundamental understanding of how the brain processes the forms and compositions of architecture. Finally, Ching [9] introduces the essential architectural design elements, including form, space, and order. Knowledge of these elements is crucial in discussions about how architectural composition contributes to buildings' overall aesthetic and visual coherence.

Together, the references provide a comprehensive understanding of the relationship between architectural elements' design and their aesthetic appeal. They highlight the importance of studying the correlation between specific design types and architectural objects' visual and aesthetic characteristics.

Those objects, especially multifamily buildings, are composed of many standardized elements, such as walls or windows. Each of these elements forms a particular whole (the building), which, as a collection, interacts with the viewer and evokes specific aesthetic sensations. According to Birkhoff and Eysenck's theory, the aesthetics of such objects are measurable and depend on the parameter C, which is the complexity of the object, and the parameter O, which is the regularity of the whole system and the individual elements. The relevance and scientific value of these methods have been repeatedly confirmed [10,11], although their application in the context of architecture has so far been mainly limited to existing objects [12]. However, the relationship between aesthetics and regularity was already pointed out by the predecessor of empirical aesthetics—Gustav Theodor Fechner [13]. The results of research in the field of experimental psychology also indicate the relationship between visual regularity and the aesthetics of an object. Four experiments by the team of Pecchinenda, Bertamini, Makin, and Ruta [14] should be mentioned. The results clearly show a preference for patterns and symbols characterized by bilateral symmetry over objects without this feature. Studies on preferences for geometric patterns also show a similar tendency. Patterns based on fractals, i.e., highly ordered (regular) structures, are considered more aesthetic than random patterns [15–17].

Furthermore, abstract patterns are more positively associated when their regularity is greater [18]. In the context of architecture, the same validity is confirmed by the study of the team of Malewczyk, Taraszkiewicz, and Czyż [19]. Statistical analyses of the survey results clearly show that more regular facades are perceived as more aesthetic. Other studies addressing these issues are also worth noting. Sussman and Ward [20], on the basis of studies using an eye-tracking apparatus, indicate that people tend to overlook empty facade spaces and uninteresting glass facades. Extreme visual regularity can be combined with monotony, and this monotony can negatively affect the audience of such architecture [21]. Very high visual repetition can even cause the atrophy of gray brain cells [22,23]. There are also positions that suggest the need to find a balance between overwhelming regularity and exaggerated, chaotic irregularity [24–26].

In the case of an architectural object, the composition is responsible for visual regularity and, therefore, the parameter O—visual order (in Birkhoff and Eysenck's formula). According to Rob Krier [27], the facade is the most important architectural element determining its aesthetic value. Secondly, for both Arnheim [3] and Alexander [12], the order is created by the geometry of the facade and, thus, among other things, by its composition. Thirdly, like regular structures, ordered structures display a strong sense of wholeness and evoke a robust perceptual response [28–30]. Attention should also be paid to the proposal of the team of Meddahi and Boussur [31] regarding the parametric description of the facade order in the context of the Eysenck method. This proposal makes the order of the facade dependent on features such as symmetry, repeatability, or coherence, among others. According to the authors of this study, these features can describe any regular composition, which also suggests a relationship between the O (order) parameter and the facade's composition.

In conclusion, the cited theories and empirical results demonstrate the relationship between visual regularity and aesthetic preferences. It should be noted, however, that these conclusions are based on studies based on the traditional understanding of beauty, for Western cultures, as pleasure derived from aesthetic sensations. Such an understanding of beauty corresponds, however, with the critical element for this study, which is the typology of composition developed by Malewczyk, Taraszkiewicz, and Czyż [1], referring to the facades of Polish multifamily residential buildings. Culturally, Poland is a Western country, and analyses of this typology in the context of aesthetic categories should be based on the Western way of understanding these categories. The general correlation from the quoted sources is that the more regular a visual stimulus is, the more aesthetically pleasing it is perceived to be.

In the case of buildings, visual regularity is determined by the composition of the elements. Therefore, it is necessary to determine the correlation between composition type and the level of visual regularity, which makes it possible to assume how the six defined composition types [1] correlate with the aesthetic qualities of an architectural object. Visual regularity is a crucial concept that will be analyzed in the following subsection.

1.2. Regularity

Regularity is a multidimensional concept. However, the authors suggest that, for the purpose of this study, it should be considered as a continuum, with completely regular (ordered) systems at one end and completely random (chaotic) systems at the other. This way of thinking about visual regularity is more than just a theoretical assumption. The research by Kubilius, Wagemans, and Op de Beeck [32] confirms a linear change in the response of specific brain areas with a change in stimulus regularity. The way the brain responds is also essential for these considerations. Previous studies have shown the appearance of responses to regular stimuli and no reactions to irregular stimuli [28–30]. Irregularity is, therefore, not something separate that would trigger an opposite reaction in the brain. Hence, the regularity of the stimulus should be considered as the degree of intensity of this feature, where complete irregularity means a lack of regularity. However, Rudolf Arnheim reached the same conclusions intuitively [3], which only proves the possibility of behavioral analysis of these phenomena.

The studies conducted so far also demonstrate the relationship between regularity (or the lack thereof) and the size of the pattern elements, the distances between the elements, and their position [33]. Also worth noting are the studies on the perception of symmetry, which is an attribute of the most regular compositions. For example, they demonstrate the automaticity of the symmetry perception process, for which specific brain structures are responsible [34]. Therefore, according to the authors, it can be assumed that the perception of regularity is an objective phenomenon resulting from the solid biological basis of this process. It is also likely that the level of regularity of certain stimuli will have a similar effect on the perception of different recipients.

Nevertheless, the method's characteristics should also be considered when assessing the degree of regularity. This method is not sensitive to composition distortion at 5% of the distance between the elements. Therefore, slight shifts in the elements do not affect the system's perception. In addition, the number of components of the set analyzed is significantly limited and may depend on the individual's characteristics [35].

Despite the existence of many studies on the perception of regular and irregular patterns or the perception of symmetry, this issue has yet to be investigated in the context of architecture. The studies cited in Section 1.1, proving observers' overlooking of monotonous or empty facade elements [20], the negative perception of monotonous architecture [21], and its harmful effects on the human brain [22,23], point out that this problem is universal to the human race in general, and also with regard to architecture. The question then remains, what do we perceive as regular and as irregular?

1.3. Aims of the Study

Modern architecture, predominantly residential, very often operates with aesthetics based on visual irregularity [36]. At the same time, in the authors' opinion, this topic has yet to be studied in sufficient depth. Designers' lack of knowledge of how their artwork will interact with potential viewers can result in artwork that is mismatched to the needs of its users. According to the sources quoted, visual regularity correlates positively with aesthetic preferences. Moreover, regularity is perceived by the human race in general in a very positive way, which is due to neuropsychological determinants. In addition, the extension of empirical research on the perception of regularity in the context of architecture and such elementary particles of it as composition provides an opportunity to explore a new area of study and, at the same time, develops the possibility of shaping the aesthetics of architectural objects "from below" (von Unten—according to the empirical tradition). This approach aligns with the contemporary interest in experimental aesthetics and neuroaesthetics in architectural design.

The purpose of this study is to determine, by empirical means, the degree of visual regularity depending on the composition type of the facade, as defined by the authors Malewczyk, Taraszkiewicz, and Czyż [1]. As mentioned earlier, determining how the statistical viewer perceives the composition would allow for projections based on these perceptions more specific to the potential viewer. This study aims to answer the following research questions:

1. Is there a relationship between the type of facade composition and its degree of regularity?
2. Which types of composition are the most regular, and which are the least?
3. Does the degree of regularity of the facade composition depend only on the type of composition?
4. Has the presentation of stimuli in different configurations influenced the determination of the degree of regularity?

The authors focus on examining compositional patterns in themselves, isolated. This approach excludes interactions between the architecture's various components, such as the overall form of the object, scale, material, or others. The authors also decided to eliminate a factor related to how architecture is perceived, which is subjected to perspective distortions in natural perception. In the authors' opinion, learning about such raw results and confronting them in the future with the results of a broader study that considers all those aspects of architecture and its perception that were excluded in the present study will become of additional value. It will allow us to explore the principles of interaction between the components of architectural objects, including architectural composition, which is the subject of the analyses contained in this study.

This study is based on the statistical analysis of a survey conducted on a random group of 48 respondents. The Materials and Methods, Results, and Discussion chapters describe the study, its results, and its conclusions.

2. Materials and Methods

2.1. Participants

Since the study was conducted based on universal neuropsychological determinants of the perception of visual regularity, which are expected of the entire human race (see Section 1.2), the minimum sample size (N) was set at 30. The above assumption was made based on the Central Limit Theorem. This is the minimum number, justifying a normal distribution in the statistical analyses of the collected survey results. According to the literature, the minimum sample size for survey scales (for example, the Likert scale used in this article) is 31.61 ± 2.33 ($p < 0.05$) [37]. The sample size in this described study meets both requirements and is representative of the general Polish population.

Respondents were randomly recruited from first-year Architecture and Spatial Management students studying at the Faculty of Architecture at the Gdańsk University of Technology. Participation in the survey was anonymous and voluntary.

2.2. Materials

2.2.1. Stimuli

For the survey, 12 abstract graphics were prepared, representing the compositions of black rectangles on a white background. All graphics are based on a square of the same size (1200×1200 px). The compositions were designed based on the definition of types of facade compositions for contemporary Polish residential and multifamily buildings [1]. The specified six types (marked with letters from A to F) cover the entire spectrum of possible types of arrangements of architectural elements (such as windows or balconies) on the facades of multifamily buildings. Based on the definitions of these six composition types, it is possible to create an infinite number of composition variations, even selecting different sizes of elements. However, the authors of this study decided to prepare two stimuli for each of the six composition types. A total of 12 stimuli were ready. In limiting the number of stimuli to 12, the authors were guided by a desire to minimize the risk of falsifying results due to respondents' lassitude.

Stimuli A1 and A2. These compositions (Figure 2) were designed according to the definition of composition type A [1].

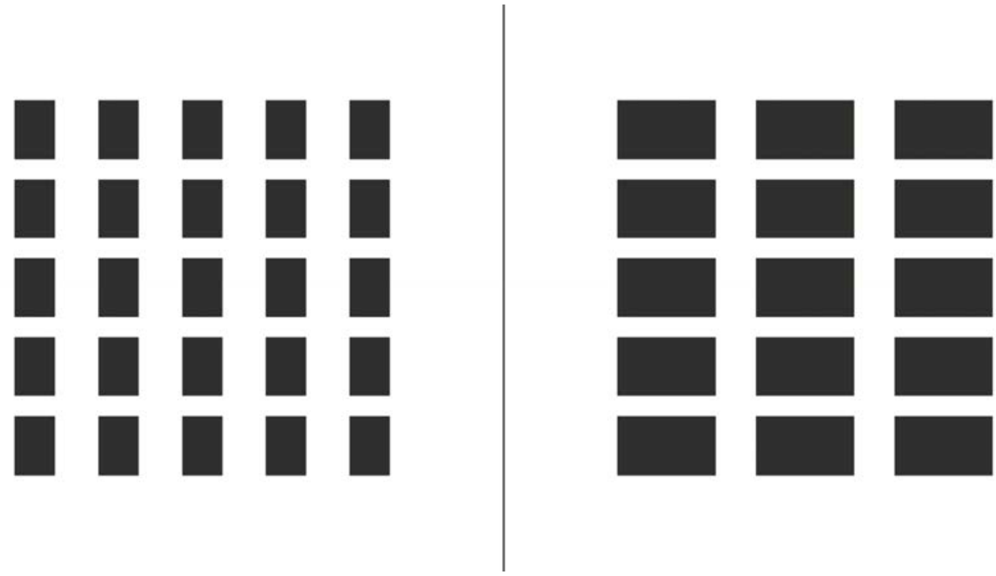

Figure 2. Compositions A1 (**left**) and A2 (**right**) presented during the research.

Compositions A1 and A2 differ in the size and quantity of the composition elements.

Stimuli B1 and B2. These compositions (Figure 3) were designed according to the definition of composition type B [1].

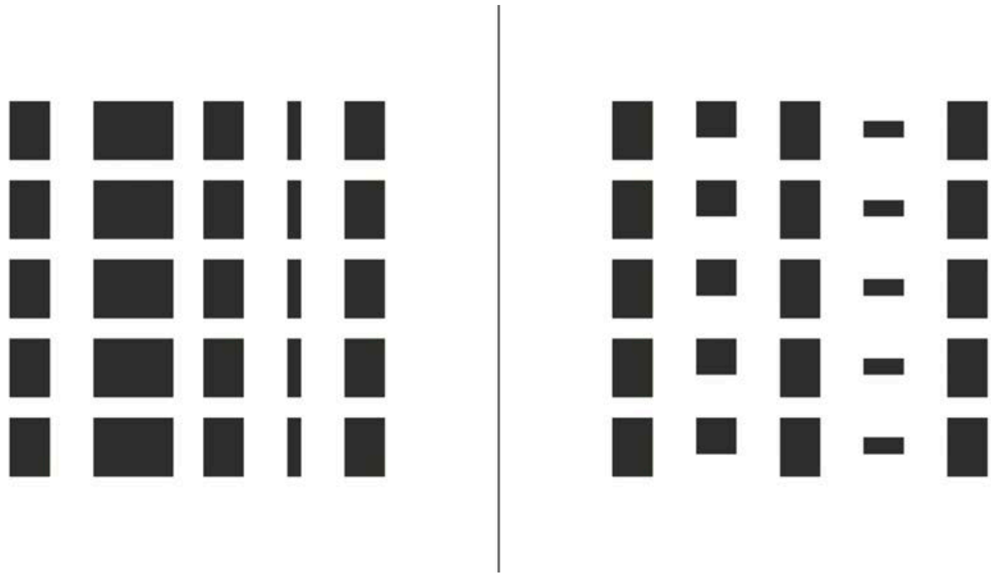

Figure 3. Compositions B1 (**left**) and B2 (**right**) presented during the research.

Composition B1 has elements with different widths but constant heights. Composition B2 has elements of the same width but different heights. The horizontal distances between the composition elements are different in the case of Composition B1 (two types) and the same in the case of Composition B2. The vertical spacing between the composition elements is the same for both compositions.

Stimuli C1 and C2. These compositions (Figure 4) were designed according to the definition of composition type C [1].

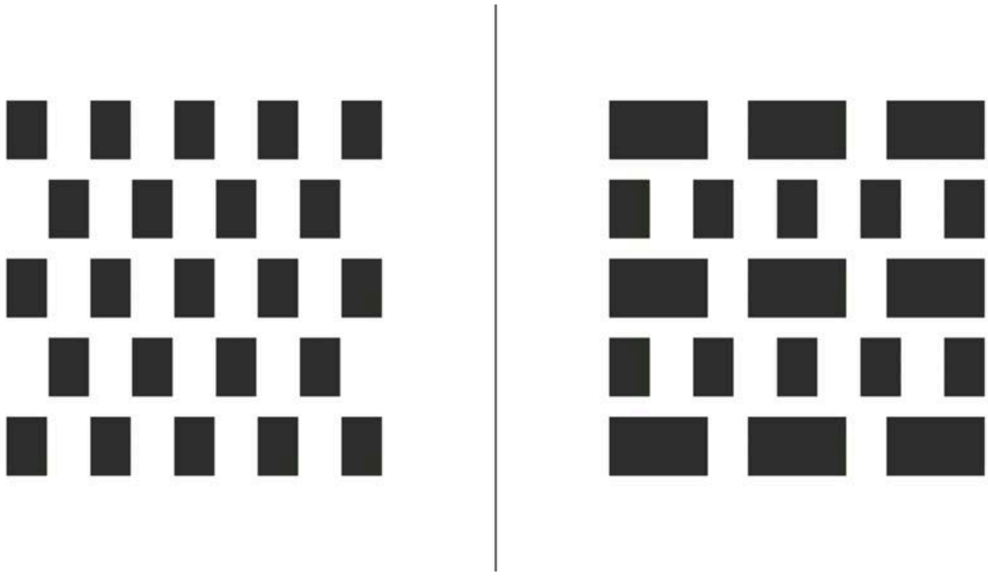

Figure 4. Compositions C1 (**left**) and C2 (**right**) presented during the research.

Composition C1 is based on one type of compositional element, and Composition C2 is based on two types of compositional elements that differ in width. The horizontal and vertical distances between the compositional elements are the same for both compositions.

Stimuli D1 and D2. These compositions (Figure 5) were designed according to the definition of composition type D [1].

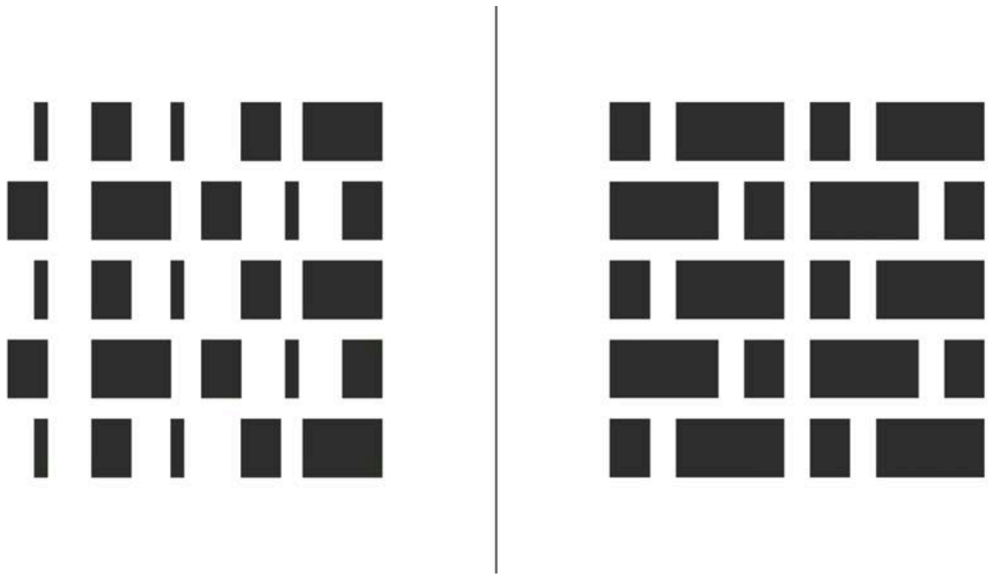

Figure 5. Compositions D1 (**left**) and D2 (**right**) presented during the research.

Composition D1 was based on three types of compositional elements with different widths but equal heights. In the odd lines, there are three different horizontal spacings between compositional elements, and in even lines, there are two types of distances. Composition D2 was based on two types of composition elements with different widths but the same heights. The horizontal spacing between compositional elements is the same in odd and even lines. The vertical intervals between the composition elements are the same in both compositions.

Stimuli E1 and E2. These compositions (Figure 6) were designed according to the definition of composition type E [1].

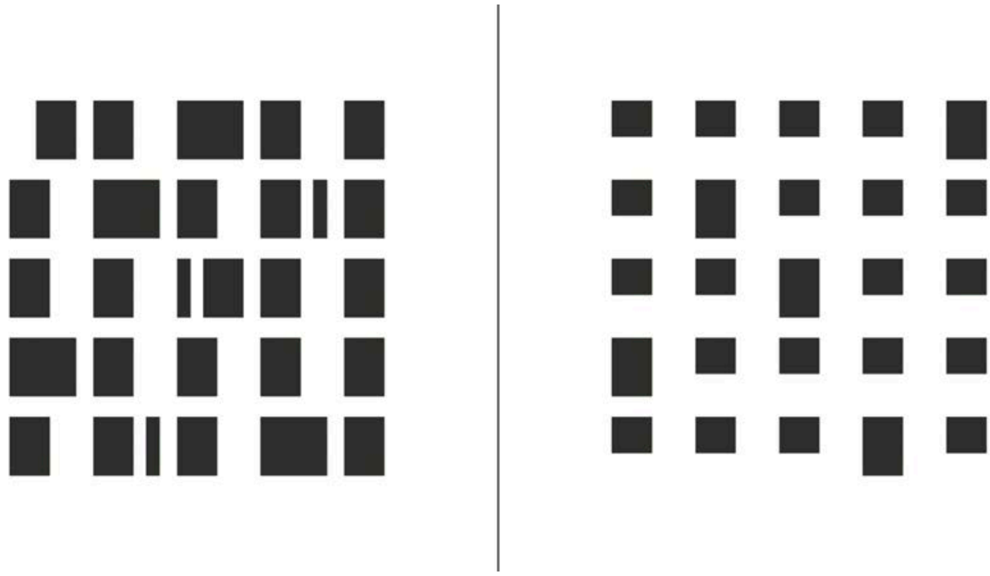

Figure 6. Compositions E1 and E2 presented during the research.

Composition E1 is based on three types of composition elements with different widths but the same heights. The horizontal distances between the compositional elements are varied and distinct in the following rows of compositional elements, and the vertical distances between the compositional elements are the same. Composition E2 is based on two types of compositional elements with equal widths but different heights. The horizontal distances between the compositional elements are the same, but the vertical distances between the elements are varied and different in successive columns of compositional elements. In both compositions, the compositional elements are arranged so that the side edges of these elements form lines (vertical in the E1 composition and horizontal in the E2 composition).

Stimuli F1 and F2. These compositions (Figure 7) were designed according to the definition of composition type F [1].

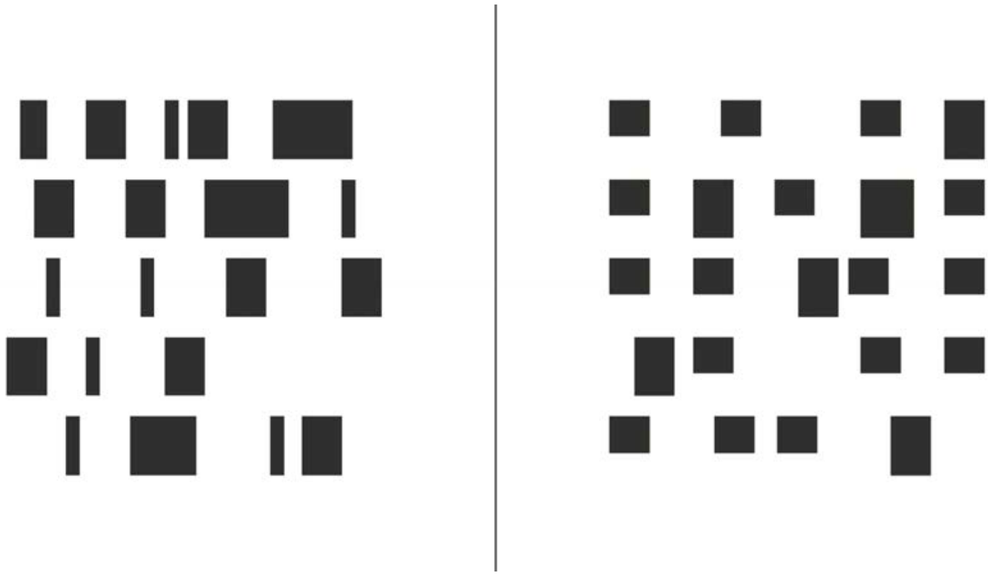

Figure 7. Compositions F1 (**left**) and F2 (**right**) presented during the research.

Composition F1 was designed based on three types of composition elements with different widths but the same heights. Composition F2 was also designed based on three types of compositional elements but with two different widths and two different heights. In the case of both compositions, the horizontal distances between the compositional elements are varied and random; in addition, in the case of composition F2, the vertical distances were also differentiated (two types of vertical distances), marked by the side edges of the compositional elements.

2.2.2. Online Questionnaire

An online questionnaire was created using the QuestionPro.com platform to conduct the survey. The questionnaire had six sections. Access the questionnaire at the following link: https://questionpro.com/t/AQjS0Zlfmd (accessed on 2 May 2023).

Section 1. This section included an introduction to the study, including information about the purpose of the study, the time frame for completing the questionnaire, and the complete anonymity of the respondents. An email contact for one of the authors was also provided.

Sections 2–5. Participants were asked to rate six visual stimuli on a Likert scale in these four sections. A six-point scale was used due to the corresponding number of composition types. A 1 on the scale indicates the most irregular stimulus, and a 6 indicates the most regular stimulus. The stimuli in each section were presented simultaneously. In each section, the stimuli were presented in a different configuration. In each section, one example of each composition type was presented simultaneously; in other words, no two examples of the same composition type were presented simultaneously. The stimuli were presented in randomized order, as shown in Table 1. Each stimulus was evaluated twice.

Table 1. The order in which visual stimuli are displayed in Sections 2–5 of the questionnaire.

Section/Order No.	1.	2.	3.	4.	5.	6.
Section 2	A1	C2	F1	B2	D2	E1
Section 3	E2	A2	C1	F2	B2	D1
Section 4	E1	B2	C1	A1	D2	F2
Section 5	C2	F1	D1	A2	E2	B1

Section 6. This section included three questions designed to collect information specific to the survey group, i.e., gender, age, and education.

2.3. Procedure

The survey was made available to first-year Architecture and Spatial Management students at the Faculty of Architecture at the Gdańsk University of Technology. The online questionnaire was distributed (as an HTTP link) via the e-learning platform and was available from 16 to 19 March 2021. Participation in the survey was completely anonymous and voluntary.

Respondents were asked to complete an online questionnaire described in the Materials subsection. The questionnaire could be completed on any computer or mobile device with a web browser and Internet access.

2.4. Statistical Analysis

For statistical analyses, a one-way ANOVA and a post hoc test were chosen as the primary tools for analyzing averages between different groups to look for statistically significant differences. Post hoc tests of one-way ANOVA show differences in means between specific groups and allow them to be precisely identified.

The GLM procedure was also selected for analysis as a tool for verifying repeated results (respondents evaluated each stimulus twice).

3. Results

The questionnaires were completed by 66 respondents, of which 18 responses were incomplete and, thus, were discarded. The study included 48 (N = 48) people aged 19 to 55 years

(M = 22.60; SD = 7.75), of whom 33 were women (68.75%) and 15 were men (32.25%). In total, 41 people (85.42%) had secondary education, and 7 (14.58%) had higher education.

The Cronbach coefficient for a total of 24 composition ratings according to a 6-point Likert scale was .93, which means that the test's reliability is excellent.

3.1. Research Question 1

To answer Research Question 1 (is there a relationship between the type of facade composition and its degree of regularity?), a one-way ANOVA was carried out in a one-way variant between groups. The dependent variable (DV) is the degree of regularity, on a scale from 1 (the least regular) to 6 (the most regular), and the independent variable (IV) is the type of composition (described with letters from A to F) to which the presented stimuli belonged. This test is designed to show whether there are statistically significant differences in the average level of visual regularity depending on the type of composition. Table 2 summarizes the results obtained during the above process.

Table 2. Summary of ANOVA for the variable "degree of regularity" depending on the type of composition.

	SS	df	MS	F
Between groups	2636.87	5.00	527.37	480.56 **
Within groups	1204.97	1.10	1.10	
Total	3841.84	1.10		

** $p < 0.001$.

The analysis of variance proved statistically significant: F (5.1) = 480.56, $p < 0.001$, η2 = 0.686, where the composition's regularity level is a function of its type.

Post hoc tests were performed to determine which composition types differed significantly in their degree of regularity. The assumption of equality of variance was rejected, and Dunnett's T3 test was used as the result of Levene's test for DV was statistically significant ($p < 0.001$). The analysis results show a statistically significant difference ($p = 0.05$) between all types of compositions, except for types B and D.

3.2. Research Question 2

To answer Research Question 2 (which types of composition are the most regular and which are the least?), descriptive statistics were carried out, which are presented in Table 3. The DV in these calculations is the degree of regularity (on a scale from 1—the least regular—to 6—the most regular), and the IV is the type of composition (described by letters from A to F) to which the presented stimuli belonged. The results of the analyses clearly show the gradation of the regularity of the composition according to its type. The most regular is type A (M = 5.842; SD = 0.470), and the second is type C (M = 5.163; SD = 0.903). Although the descriptive statistics show differences between the degree of regularity of composition types B (M = 4.054; SD = 1.296) and D (M = 3.696; SD = 1.404), these differences are not statistically significant, as shown via the post hoc tests performed (see the results for Research Question 1). Therefore, it can be assumed that the compositions of type B and D are ex aequo third in the ranking of the degree of regularity. Type E is in fourth place (M = 2.228; SD = 1.072). Type F compositions are considered the least regular (M = 1.402; SD = 0.804).

3.3. Research Question 3

To answer Research Question 3 (does the degree of regularity of the facade composition depend only on the type of composition?), a one-way ANOVA was performed between groups. The DV is the degree of regularity (on a scale from 1—the least regular—to 6—the most regular), the IV is the subtype of the composition, i.e., an example of a composition of a given type, described by a combination of letters denoting the general type of the composition (from A to F) and a numerical value indicating the version of the composition of a given type (1 or 2). This test is designed to show whether there are statistically significant differences in the average level of visual regularity depending on the subtype of composition. A summary of the results obtained during the operation described above is given in Table 4.

Table 3. Descriptive statistics for the "degree of regularity" DV against composition types.

	Type A	Type B	Type C	Type D	Type E	Type F
Standard Deviation	0.470	1.296	0.903	1.404	1.072	0.804
Confidence	0.068	0.187	0.117	0.203	0.155	0.116
Standard error	0.035	0.096	0.060	0.104	0.079	0.059
Min. value	5.808	3.959	5.104	3.592	2.149	1.343
Mean value	5.842	4.054	5.163	3.696	2.228	1.402
Max. value	5.877	4.150	5.223	3.799	2.307	1.461

Table 4. Summary of ANOVA for the variable "degree of regularity" by composition subtype.

	SS	df	MS	F
Between Groups	2703.35	11.00	245.76	235.72 **
Within Groups	1138.49	1.09	1.04	
Total	3841.84	1.10		

** $p < 0.001$.

ANOVA proved statistically significant: F (11.1) = 235.72, $p < 0.001$, η2 = 0.704, demonstrating the relationship between the level of regularity and the subtype of composition (a particular, exemplary composition).

Post hoc tests were carried out to determine which composition examples differed significantly concerning the degree of regularity. The assumption of the equality of variance was rejected as the result of Levene's test for the variable "degree of regularity" was statistically significant ($p < 0.001$), and Dunnett's T3 test was used. There were statistically significant ($p = 0.05$) differences between all pairs of elements except A1:A2, B1:B2, B1:D2, B2:D2, E1:E2, and F1:F2. Descriptive statistics were also performed on the "degree of regularity" variable as a function of composition subtype. Tables 5 and 6 show the results of these statistics.

Table 5. Distribution of DV in relation to the stimuli A1, A2, B1, B2, C1, C2.

	A1	A2	B1	B2	C1	C2
Standard Deviation	0.490	0.452	1.309	1.291	0.713	1.002
Confidence	0.100	0.092	0.267	0.264	0.119	0.205
Standard Error	0.051	0.047	0.136	0.135	0.061	0.104
Min. value	5.797	5.790	3.907	3.931	5.352	4.809
Mean value	5.848	5.837	4.043	4.065	5.413	4.913
Max. value	5.899	5.884	4.180	4.200	5.474	5.017

Table 6. Distribution of DV in relation to the stimuli D1, D2, E1, E2, F1, F2.

	D1	D2	E1	E2	F1	F2
Standard Deviation	1.377	1.251	0.889	1.190	0.802	0.810
Confidence	0.281	0.256	0.182	0.243	0.164	0.165
Standard Error	0.144	0.130	0.093	0.124	0.084	0.084
Min. value	3.052	4.065	1.907	2.332	1.340	1.296
Mean value	3.196	4.196	2.000	2.457	1.424	1.380
Max. value	3.339	4.326	2.093	2.581	1.507	1.465

There are statistically significant differences ($p = 0.05$) between the compositions C1 (M = 5.413; SD = 0.713) and C2 (M = 4.913; SD = 1.002) and between D1 (M = 3.052; SD = 1.377) and D2 (M = 4.065; SD = 1.251). In addition, in the case of the D2 composition (M = 4.196; SD = 1.251), the degree of regularity is greater than the general degree of regularity of type B (M = 4.054; SD = 1.296) and at the same time greater than the degree of regularity of subtypes B1 (M = 4.043; SD = 1.309) and B2 (M = 4.065; SD = 1.291).

3.4. Research Question 4

To answer Research Question 4 (has the presentation of stimuli in different configurations influenced the determination of the degree of regularity?), the GLM procedure of repeated measurements was carried out with the assumption of two levels (first and second measurement). The Bonferroni post hoc LSD test was used to evaluate the differences in the analyzed parameters. The statistical analyses showed a statistically significant difference between the results obtained for the first and second samples (i.e., for the first and second stimulus presentations) (MD = 0.071; $p = 0.05$). Two post hoc Bonferroni tests were then performed to detect differences for composition types and subtypes. The results of the above tests showed statistically significant ($p = 0.05$) differences in the first and second measurements between all composition types, except for the B:D pair. The post hoc test on the repeated measurements obtained for the composition subtypes showed statistically significant differences for all pairs except A1:A2, A1:C1, A2:C1, B1:B2, B1:D2, B2:D2, C1:C2, E1:E2, E1:F1, E1:F2, and F1:F2.

For this reason, the between-groups variant of the one-way ANOVA was repeated. In these calculations, the DV is the degree of regularity (on a scale from 1—the least regular—to 6—the most regular) for the first and second measurements. The IV is the type of composition (described by letters from A to F) to which the presented stimuli belonged. The analysis of variance was statistically significant for the first measurement $F(5.551) = 231.16$, $p < 0.001$, and the second measurement $F(5.551) = 248.98$, $p < 0.001$. Levene's test results for all variables were significant ($p < 0.001$), rejecting homogeneity and using Dunnett's T-test. The post hoc test analysis for the first and second measurements showed statistically significant ($p = 0.05$) differences in the degree of regularity for all pairs of composition types except B:D, which is consistent with the results presented earlier, described in the Results—Research Question 1 subsection.

A univariate analysis of variance (ANOVA) was conducted within an intergroup design to examine differences in the DV—the degree of regularity, which was rated on a scale ranging from 1 (minimally regular) to 6 (maximally regular), across two time points, as well as differences based on the IV—composition subtype (a categorical variable represented by combinations of letters A–F and numbers 1–2). The results of the ANOVA revealed a statistically significant effect for the degree of regularity at the first time point, $F(11.551) = 111.26$, $p < 0.001$, and at the second time point, $F(11.551) = 123.93$, $p < 0.001$. Levene's test for equality of variances for the degree of regularity indicated significant violations of the homogeneity of variance assumption at both time points ($p < 0.001$), leading to the rejection of this assumption. Consequently, Dunnett's T3 post hoc test was employed for pairwise comparisons. The analyses comparing the degree of regularity across different composition subtypes, both in the aggregated results as presented in the "Results—Research Question 1" section and separately for the first and second time points, are detailed in Table 7, highlighting the absence of statistically significant differences among the composition subtypes.

Thus, discrepancies were noted in the context of statistically significant differences ($p = 0.05$). The B1:D1 and D1:D2 pairs differed significantly in the degree of regularity in the overall results and the second sample. The C1:C2 pair differed only in the overall results.

Table 7. Comparison of the results of the one-way ANOVA in terms of the lack of statistically significant differences in the degree of regularity between the pairs of compositions for the sum of both measurements and separately for the first and second measurements.

	A1 A2	**A1 C1**	**A2 C1**	**B1 B2**	**B1 C2**	**B1 D1**	**B1 D2**	**B2 C2**	**B2 D1**	**B2 D2**	**C1 C2**	**C2 D2**	**D1 D2**	**D1 E2**	**E1 E2**	**E1 F1**	**E1 F2**
1 + 2	x			x			x			x					x		
1	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	
2	x			x	x		x	x	x	x	x	x		x	x	x	x

4. Discussion

This study ranked the types of compositions according to their degree of regularity. For this purpose, a questionnaire survey was conducted, and statistical analyses were performed.

4.1. Research Question 1

Statistical examinations addressed Research Question 1, which probes the association between facade composition type and its regularity degree. These analyses elucidate the correlation between the composition type and its regularity level. The findings indicate a variance in the regularity degree among all composition types, barring types B and D, between which the regularity does not exhibit a statistically significant difference. The absence of a statistically significant discrepancy in the regularity degree between types B and D could be attributed to the nuanced distinctions between these composition types. These compositions are defined in entirely different ways and have completely different constraints. At the same time, it can be assumed that the specific stimuli prepared for the study are within the tolerances Morgan wrote about [35].

4.2. Research Question 2

A series of descriptive analyses were performed to elucidate Research Question 2 concerning the identification of composition types with the highest and lowest levels of regularity. These analyses revealed a distinct hierarchy of regularity among the composition types. Composition type A was identified as exhibiting the highest degree of regularity, attributed to its uniform elements spaced at equal intervals. In contrast, composition type F was the most irregular, disregarding compositional rules. This includes randomness in the sizes and proportions of elements, as well as their placement and spacing. Following type A in terms of regularity is type C, which can be regarded as a derivative of type A compositions. More precisely, type C represents an amalgamation of two exemplary type A compositions, positioning it as the second most regular composition type.

Although descriptive statistics show that type B compositions are more regular than type D, statistical analyses indicate that these differences are not statistically significant. This is interesting because type D is a composite of two type B compositions. Type A compositions, for example, are considered significantly more regular than type C compositions, a combination of two type A compositions. Such results suggest that a person's ability to judge the regularity of stimuli with a moderate intensity of this property is limited. Judgments are unambiguous for stimuli near the extremes of the regularity scale, but judgments become less differentiated for stimuli near the middle of the scale.

The second least regular composition type is type E, demonstrating that theoretical vertical composition lines are much less legible than a group of harmonious elements arranged in a vertical column. These results clearly correlate with Arnheim's observations on the verticality of buildings [3]. Although abstract graphics were presented in the study, the vertical direction is perceptually perceived as superior to the horizontal.

Therefore, the vertical axes of the composition and the relationships between them are most important in determining the composition's degree of regularity (or irregularity). The more precise the lines of the composition and the smaller the differences in the horizontal distances between the axes, the more regular the composition is perceived. To some extent, this is also confirmed by the experiment conducted by Friedenberg and Bertamini [30], who proved the supremacy of the vertical direction in perceiving the symmetry of abstract elements.

Referring to the results of the statistical analyses conducted to answer Research Questions 1 and 2 and the cited literature [14–19], facades based on type A and C compositions should provide the most pleasant visual experience. However, it should be noted that they are the most repetitive. Therefore, it is worth asking how to design facades based on these compositions while avoiding monotony. Indeed, when designing based on these types of compositions, according to the theory of Birkhoff and Eysenck [10–12], one should maintain the most significant possible degree of complexity.

4.3. Research Question 3

To answer Research Question 3 (does the degree of regularity of the facade composition depend only on the type of composition?), statistical analyses were performed. The results of the calculations prove that the degree of regularity of the subtypes (specific exemplary compositions) of the compositions of types A, B, E, and F is similar (there are no statistically significant differences). Therefore, it can be assumed that regardless of the individual characteristics of specific examples of compositions of type A, B, E, or F, the degree of regularity will be consistent with the degree of regularity of the type as a whole. The opposite relationship has been observed in the context of composition types C and D. Thus, a composition of type D may be more regular than a composition of type B due to individual characteristics.

It should be noted that stimulus D2 as a composition consists of two layers (Figure 8), according to the multilayer composition model [38], where individual elements form a D type composition. Still, as groups, they create an A type composition. The statistical analyses of the degree of regularity in composition subtypes also revealed differences between D2, B1, and B2 compositions. Moreover, the descriptive statistics show that the stimulus D2 was classified as more regular than the type of composition B. Therefore, studies based on a more significant number of stimuli from the group of types of compositions B and D would show a difference between these types and, simultaneously, a greater regularity of B types relative to D types.

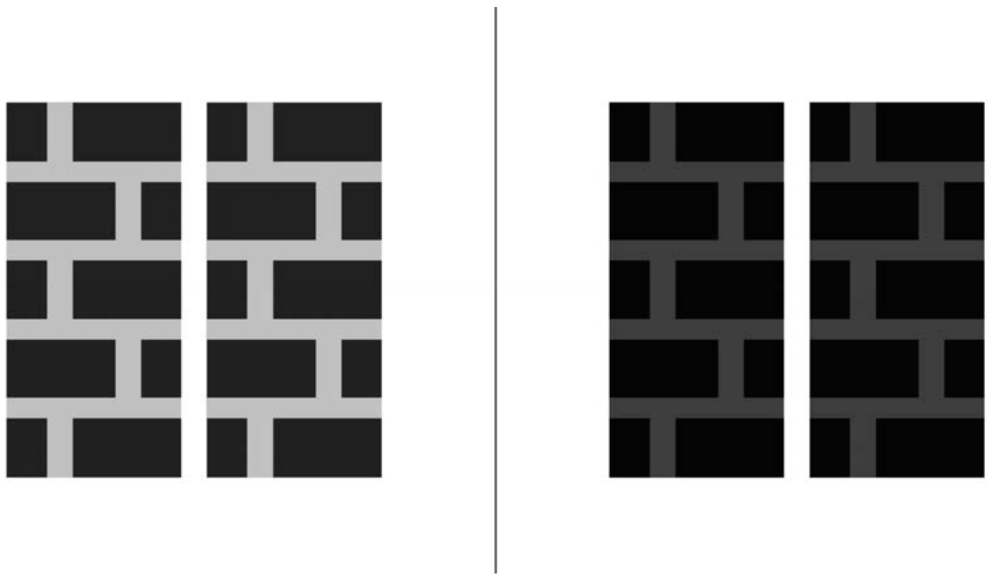

Figure 8. Division of the D2 stimulus into compositional layers—type D (**left**) and A (**right**).

Nevertheless, the degree of regularity in this context may depend not only on the type of composition itself but also on the types of individual compositional layers and individual features. Based on the results presented, this is only true for compositions C and D. These results somewhat agree with previous studies that demonstrate a relationship between regularity and features such as element size or distances between elements [33]. The type of composition, on the other hand, defines how the elements are organized rather than the elements themselves.

4.4. Research Question 4

To answer Research Question 4 (has the presentation of stimuli in different configurations influenced the determination of the degree of regularity?), statistical analyses were performed. The results show that the determination of the global degree of regularity of the composition type is independent of other factors. It can be concluded that, for example, type A compositions will always be perceived as more regular than type C compositions.

Nevertheless, stimulus presentation conditions are statistically significant in determining the regularity of specific compositions. Thus, compositions appear regular depending on which other composition they are combined with.

The statistical evaluation of the degree of regularity, segmented by types and composition subtypes across the initial and subsequent measurements, unequivocally demonstrated that the configuration of stimulus presentation exerts a statistically significant influence on the appraisal of stimulus regularity. This phenomenon aligns with findings from prior research, which identified a comparable impact within the context of dot pattern regularity perception, influenced by the regularity degree of the encompassing pattern [19]. Rudolf Arnheim's work [39] offers partial corroboration of this effect, elucidating the principle of similarities and dissimilarities. According to Arnheim, this principle posits that stimuli have the potential to either mitigate or amplify each other's effects, thus affecting the overall perception of regularity.

5. Conclusions

To investigate the link between facade composition types [1] and their perceived visual regularity, a study involving 48 anonymous participants was conducted via an online survey. Participants were tasked with assessing visual stimuli—created based on composition definitions by Malewczyk, Taraszkiewicz, and Czyż [1]—using a Likert scale. The gathered data underwent statistical analysis.

Throughout the survey execution and subsequent data analysis, the authors addressed all four posed research questions. However, the findings still need to elucidate the observed phenomena fully. The results presented in Section 3.1 and further discussed in Section 4.1 highlight the ambiguity regarding the regularity of B type and D type compositions. Furthermore, results indicated that the degree of regularity is influenced by the composition type and its unique characteristics and integration with other compositions (see Sections 3.3, 3.4, 4.3 and 4.4). Research is needed to explain the reasons behind these dependencies.

The authors recommend further research to examine the regularity of composition types B and D, how specific compositional techniques affect regularity, and investigate environmental influences on stimulus perception. It may also be beneficial to increase the number of stimuli from the same compositional type to minimize the impact of unique stimulus characteristics on the overall findings for that type. Such expanded research could enhance the understanding of composition perception regarding compositional typology and irregularity levels.

Crucially, this study connected composition type and visual regularity. According to Sections 3.2 and 4.2, compositional types A and C are perceived as the most regular. In contrast, types E and F are considered least regular, with B and D types falling into a moderate regularity category. Given the study's foundation on the universal neurobiological basis of visual regularity perception, the authors suggest that these findings broadly apply to the Polish population. An international study is recommended to extend these findings universally, although significant variations in results across cultures are yet to be anticipated.

It is vital to note that this study was conducted without considering the multidimensional and interactive nature of architectural perception. For more comprehensive insights, future research should integrate these aspects, answering whether composition defines architecture absolutely or relatively in light of its multifaceted characteristics.

Author Contributions: Conceptualization, M.M. and P.C.; methodology, M.M. and P.C.; software, M.M.; validation, A.T. and P.C.; formal analysis, M.M.; investigation, M.M.; resources, M.M.; data curation, M.M.; writing—original draft preparation, M.M.; writing—review and editing, A.T. and P.C.; visualization, M.M.; supervision, A.T.; project administration, M.M., A.T. and P.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Malewczyk, M.; Taraszkiewicz, A.; Czyż, P. Composition patterns of contemporary Polish residential building facades. *Nexus Netw. J.* **2022**, *24*, 767–785. [CrossRef]
2. Lang, J. *Creating Architectural Theory: The Role of the Behavioral Sciences in Environmental Design*; Van Nostrand Reinhold: New York, NY, USA, 1987.
3. Arnheim, R. *The Dynamics of Architectural Form*, 1st ed.; The Regents of the University of California: Oakland, CA, USA, 1977.
4. Bovill, C. *Fractal Geometry in Architecture and Design*; Birkhäuser: Basel, Switzerland, 1996.
5. Mandelbrot, B.B. *The Fractal Geometry of Nature*; W.H. Freeman and Co.: New York, NY, USA, 1982.
6. Ramachandran, V.S.; Hirstein, W. The Science of Art: A Neurological Theory of Aesthetic Experience. *J. Conscious. Stud.* **1999**, *6*, 15–51.
7. Joye, Y. Architectural Lessons from Environmental Psychology: The Case of Biophilic Architecture. *Rev. Gen. Psychol.* **2007**, *11*, 305–328. [CrossRef]
8. Zeki, S. *Inner Vision: An Exploration of Art and the Brain*; Oxford University Press: Oxford, UK, 1999.
9. Ching, F.D.K. *Architecture: Form, Space, & Order*; John Wiley & Sons: Hoboken, NJ, USA, 1996.
10. Davis, R.C. An evaluation and test of Birkhoff's aesthetic measure formula. *J. Gen. Psychol.* **1936**, *15*, 231–240. [CrossRef]
11. Eysenck, H.J. The empirical determination of an aesthetic formula. *Psychol. Rev.* **1941**, *48*, 83–92. [CrossRef]
12. Alexander, C. *The Nature of Order: The Phenomenon of Life*, 1st ed.; Center for Environmental Structure: Berkeley, CA, USA, 2002.
13. Fechner, G.T. *Vorschule der Aesthetik*, 1st ed.; Breitkopf and Härtel: Wiesbaden, Germany, 1876.
14. Pecchinenda, A.; Bertamini, M.; Makin, A.D.J.; Ruta, N. The pleasantness of visual symmetry: Always, never or sometimes. *PLoS ONE* **2014**, *9*, e92685. [CrossRef]
15. Taylor, R. Fractal expressionism—Where art meets science. In *Art and Complexity*; Casti, J., Karlqvist, A., Eds.; Elsevier: Amsterdam, The Netherlands, 2003; pp. 117–144.
16. Taylor, R.; Newell, B.; Spehar, B.; Clifford, C. Fractals: A resonance between art and nature. In *Mathematics and Culture II: Visual Perfection: Mathematics and Creativity*; Emmer, M., Ed.; Springer: Berlin/Heidelberg, Germany, 2005; pp. 55–63.
17. Friedenberg, J.; Martin, P.; Uy, N.; Kvapil, M. Judged beauty of fractal symmetries. *Empir. Stud. Arts* **2021**, *40*, 100–120. [CrossRef]
18. Bertamini, M.; Makin, A.; Rampone, G. Implicit association of symmetry with positive valence, high arousal and simplicity. *I-Perception* **2013**, *4*, 317–327. [CrossRef]
19. Malewczyk, M.; Taraszkiewicz, A.; Czyż, P. Preferences of the facade composition in the context of its regularity and irregularity. *Buildings* **2022**, *12*, 169. [CrossRef]
20. Sussman, A.; Ward, J. Here's What You Can Learn about Architecture from Tracking People's Eye Movements. Available online: https://www.archdaily.com/884945/heres-what-you-can-learn-about-architecture-from-tracking-peoples-eye-movements (accessed on 26 April 2024).
21. Sawantt, S. Human Centric Design. Available online: https://blarrow.tech/human-centric-design/ (accessed on 26 April 2024).
22. Wilkins, A.J. *Visual Stress*, 1st ed.; Oxford University Press: Oxford, UK, 1995.
23. Filin, V.A. *Videoecologiya*; TASS-Reclama: Moscow, Russia, 1997.
24. Saluja, T. Chaos and Order in Architectural Design. Available online: https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a529-chaos-and-order-in-architectural-design/ (accessed on 26 April 2024).
25. Valle, G. 6 Ordering Principles Used in Architecture. Available online: https://www.yourownarchitect.com/6-ordering-principles-used-in-architecture/ (accessed on 26 April 2024).
26. Rubinowicz, P. Chaos and Geometric Order in Architecture and Design. *J. Geom. Graph.* **2000**, *4*, 197–207.

27. Krier, R. *Elements of Architecture*, 1st ed.; Academy Editions: Cambridge, MA, USA, 1992.
28. Biederman, I. Recognition-by-components: A theory of human image understanding. *Psychol. Rev.* **1987**, *94*, 115–147. [CrossRef]
29. Kayaert, G.; Biederman, I.; Op de Beeck, H.P.; Vogels, R. Tuning for shape dimensions in macaque inferior temporal cortex. *Eur. J. Neurosci.* **2005**, *22*, 212–224. [CrossRef]
30. Friedenberg, J.; Bertamini, M. Contour symmetry detection: The influence of axis orientation and number of objects. *Acta Psychol.* **2000**, *105*, 107–118. [CrossRef]
31. Meddahi, K.; Boussura, K. Aesthetic measures of algiers' colonial facades. *Nexus Netw. J.* **2021**, *23*, 667–688. [CrossRef]
32. Kubilius, J.; Wagemans, J.; Op de Beeck, H.P. Encoding of configural regularity in the human visual system. *J. Vis.* **2014**, *14*, 11. [CrossRef]
33. Sun, H.-C.; Kingdom, F.A.A.; Baker, C.L., Jr. Perceived regularity of a texture is influenced by the regularity of a surrounding texture. *Sci. Rep.* **2019**, *9*, 1637. [CrossRef]
34. Makin, A.D.J.; Rampone, G.; Wright, A.; Martinovic, J.; Bertamini, M. Visual symmetry in objects and gaps. *J. Vis.* **2014**, *14*, 12. [CrossRef]
35. Morgan, M.J.; Mareschal, I.; Chubb, C.; Solomon, J.A. Perceived pattern regularity computed as a summary statistic: Implications for camouflage. *Proc. Biol. Sci.* **2012**, *279*, 2754–2760. [CrossRef]
36. Malewczyk, M.; Czyż, P. Features of irregularity in examples of Polish multi-family architecture constructed in 2011–2021 and nominated for the Mies van der Rohe award. *Czas. Tech.* **2022**, *119*, 1–12. [CrossRef]
37. Louangrath, P. Minimum Sample Size Method Based on Survey Scales. *Int. J. Res. Methodol. Soc. Sci.* **2017**, *3*, 44–52.
38. Tayyebi, S.F.; Demir, Y. Architectural composition: A systematic method to define a list of visual attributes. *Art Des. Rev.* **2019**, *7*, 131–144. [CrossRef]
39. Arnheim, R. *Art and Visual Perception: A Psychology of the Creative Eye*, 1st ed.; University of California Press: Berkeley, CA, USA, 1954.

4.4 PUBLIKACJA IV

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Article

Preferences of the Facade Composition in the Context of Its Regularity and Irregularity

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Abstract: The aim of this study is to determine the preferences of Polish society towards building facades depending on the degree of the composition regularity of the facade elements. The subject matter is inspired by the authors' observations in relation to the current architectural trends. The purposefulness of the conducted research results from several issues. Firstly, the reports of psychology and neurosciences clearly indicate the universality of certain preferences towards visual attributes of objects (e.g., in relation to abstract symmetric patterns), resulting from biological conditions. Secondly, residential, multi-family architecture is by definition designed for a wide group of anonymous users whose expectations must be met. One of the dimensions of the above-mentioned expectations is the visual dimension, partially dependent on the composition of the facade. In the course of the conducted research, it is shown that facades with a regular composition are assessed as more attractive than those with irregular compositions. Moreover, irregular facades evoked a negative effect of a significantly greater force than the positive effect in the case of regular facades. The above-described discoveries shed, in the authors' opinion, a completely new light on the contemporary work of architects. It is extremely important to adapt the visual dimension of architecture to the expectations of its recipients, while taking care of its values and quality as a field of art.

Keywords: composition; aesthetics; multi-family housing; Poland; preferences

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Citation: Malewczyk, M.; Taraszkiewicz, A.; Czyż, P. Preferences of the Facade Composition in the Context of Its Regularity and Irregularity. *Buildings* **2022**, *12*, 169. https://doi.org/10.3390/buildings12020169

Academic Editor: Oleg Kapliński, Agata Bonenberg, Wojciech Bonenberg and Marco Lucchini

Received: 15 December 2021
Accepted: 31 January 2022
Published: 3 February 2022

1. Introduction

The main purpose of this study is to determine the aesthetic preferences of Poles depending on the degree of regularity in the composition of building facades. An additional goal is to identify these preferences depending on the type of composition. Aesthetics is naturally a very broad and complex concept, but in relation to this study, it should be considered as a visual dimension of the external part of architecture. The research further narrows the visual dimension of architecture, which is also a broad and complex phenomenon to the composition of window openings (an essential architectural element on most multi-family building facades). Such a limitation allows to limit the conclusions from the study only to the composition of window openings. These should be considered both as a pattern (according to Alexander's theory [1]) and as a component of architecture as a multi-layer composition [2] with an influence on the aesthetics of the whole building.

Therefore, a questionnaire survey was conducted among 109 people. Statistical analyses of the obtained results were used to formulate answers to research questions and conclusions. The significance of the conducted research resulted from the utilitarian nature of residential, multi-family architecture and the resulting universality. Multifamily housing constitutes the main part of the urban fabric and it is extremely important that its aesthetics meet the expectations of modern society. It is impossible to fully meet these expectations without knowing the corresponding statistical data. Although this study refers to the preferences of Poles, and, therefore, its scope is local, it refers to common preferences applicable in the analysed group. It should also be noted that the presented research method is a universal one and is a starting point for global research and for determining the preferences of the general public.

One of the key issues for this study is the concept of aesthetics. Naturally, this is a very broadly understood term [3]. Aesthetics itself is a branch of philosophy; however, aesthetics understood as the visual dimension of an object (e.g., works of art) also depends on other philosophical trends and concepts. Nowadays, we can observe the emergence of voices suggesting the need to redefine the directions in which the aesthetics of architecture should follow. In the opinion of the authors, special attention should be paid to trends relating to the aesthetics of the everyday [4], an example of which may be the Super Normal [5] initiative. Roger Scrouton [6], among others, draws attention to the importance of creating the aesthetics of architecture in the context of its impact on everyday life. Everyday architecture is also treated as a counterpoint to a world engulfed in consumerism and the necessity to follow fashion [7], a counterpoint to architecture defined by Tom Dyckhoff as "wowhaus" architecture [8]. The need to direct the way of creating architecture to its user is also indicated by Jeremy Till, who called architecture a frame for life [9]. It is very important to fill the gap between architectural monuments and people, as Till also states [9], but in the authors opinion it is not possible without obtaining the knowledge of the real expectations and preferences of ordinary users of architecture.

Another important issue for these considerations is the growing interest in irregularity in the context of shaping the visual dimension of architecture. This tendency is evidenced by many international projects, but the most important for these considerations are objects from Poland. It is worth paying attention to the Polish multi-family architecture, realized in 2011–2021 and, at the same time, nominated for the Mies van der Rohe award. During this period, seven multi-family projects were created (Figure 1) which were nominated for this prestigious award and, therefore, are examples of architecture of above-average quality. These projects inspire other architects and, above all, set trends in design and also reflect the current trends in this segment of architecture. The analysis of the facades of these objects shows that in the case of four (out of seven) implementations, we deal with irregular compositions and with irregular (in terms of texture or colour) facade materials. The two embodiments also operate in an irregular form. It should also be noted that there is a certain irregularity (formal, compositional or material) in each of the realizations. The results of the above analyses are presented in Table 1. In the opinion of the authors, it can, therefore, be concluded that we are dealing with a clear tendency related to the shaping of the contemporary aesthetics of Polish multi-family architecture.

Figure 1. Polish residential, multi-family projects nominated for the Mies van der Rohe for 2011–2021: (**a**) Atmosfera real estate; (**b**) Riverview real estate; (**c**) Nowy Werdon building; (**d**) Nowy Nikiszowiec real estate; (**e**) Unikato building; (**f**) Sprzeczna 4 building; (**g**) 19 Dzielnica real estate.

Table 1. List of irregularities in relation to the analysed housing developments.

Project Name	Designer	a	b	c
Atmosfera	arch_it		X	
Riverview	APA Wojciechowski		X	X
Nowy Werdon	Biuro Projektowe Maleccy		X	X
Nowy Nikiszowiec	22ARCHITEKCI			X
Unikato	KWK PROMES	X		X
Sprzeczna 4	BBGK	X		X
19 Dzielnica	JEMS Architekci		X	

(a) Irregularity of form. (b) Irregularity of composition. (c) Irregularity of material.

At the same time, due to the utility nature of multi-family housing, a question should be asked whether this direction is in line with the users' expectations. Doubts about the purposefulness of this aesthetic tendency arise from the results of research carried out in many different fields. Firstly, there are many studies which, based on quantitative research, indicate a clear difference between the aesthetic judgments determined by architects and non-architects [10]. Secondly, research clearly shows people's preference for objects and systems with regular features. One should pay attention to the discoveries determined in 2014 by a group of scientists—Pecchinenda, Bertamini, Makin and Ruta [11]. The results of four experiments clearly indicated a tendency to choose patterns or symbols that are symmetrical to asymmetrical. Equally important are the discoveries related to the preferences for fractal-based patterns, which are highly ordered and regular structures. Such patterns are considered to be much more aesthetic than those not based on such structures [12–14]. The same regularity was observed in relation to abstract regular patterns, which, in the research of the Bertamini, Makin and Rampone team, were associated with positively marked words. The associations with irregular patterns were opposite [15]. Thirdly, too much visual variety in the built environment can simply result in spatial chaos.

On the other hand, there are many reasons to move away from extremely repetitive facades. Reports of videoecology clearly indicate the problem of the disappearance of gray brain cells caused by exposure to environments composed of the same, repeatable elements [16,17]. Visually diverse environments also evoke much more positive reactions in recipients [18]. Therefore, it can be assumed that the clear regularity and repeatability in the case of architecture does not reflect the aesthetic needs of a human being, as the results of research by psychologists and neuropsychologists suggest. This could also suggest that we should design irregular compositions that break the monotony and predictability of regular ones. However, in the opinion of the authors, it is not possible to resolve the aesthetic dispute between regularity and irregularity without examining the actual preferences.

An extremely important issue for these considerations is also the issue of universal, biological determinants that govern the processes of perception, determining aesthetic judgments and experiencing beauty [19]. Despite the relatively short tradition of experimental aesthetics or neuroscience, attention should be paid to three publications from 2004 by Vartanian and Goel [20], Kawabata and Zeki [21] and Cela-Conde et al. [22]. All the above-mentioned teams of researchers, thanks to the technology enabling neuroimaging (fMRI or MRI), clearly indicated that when the recipient contacted an object generally considered as beautiful, the reward system was activated in the brain. The results of these studies also highlight the lack of a single structure in the brain responsible for making aesthetic judgments, which are rather the result of more complex processes. Naturally, neurosciences clearly flatten the character of aesthetic experience and may also only provide empirical confirmation of intuitive judgments about beauty [23]. Nevertheless, this approach proves the possibility of describing universal determinants of beauty, common to the general public and independent of the individual's particular characteristics.

Determining the aesthetic preferences regarding the composition of building facades in the context of the degree of their regularity is important as long as they strengthen the designers' awareness of how to shape the space. They can primarily help to determine the directions in which aesthetics should follow in order to meet the expectations of its recipients. They can also help in determining the directions in which architecture should go in order to simultaneously meet the needs and expectations of its users and, at the same time, to not cease being art. The implementation of this task, however, is the role of architects, whose knowledge should be as broad as possible. The results and conclusions of this study can also be a very powerful planning tool. The use of a specific type of composition in a given area could help with building spatial order, but also with breaking the aesthetic monotony or be an architectural reinforcement of an urban dominant.

2. Materials and Method

The aim of the study was to determine the preferences of Poles towards building facades in the context of their regularity. The study was conducted in three stages. The first step was to prepare the research material; then, an internet survey was conducted. The last stage was to carry out statistical analyses of the collected results and to formulate conclusions.

Naturally, each architectural object is a complex being, but each of its components influences the perception of the whole. This approach to the multi-element nature of architecture is reflected in the pattern language proposed by Christopher Alexander [1]. According to the authors, one of the most important patterns is the composition of architectural elements, such as window openings, balconies or elevation panels, because the way the same elements are arranged on the same facade causes its perception to be completely different. The composition also determines the complexity of the facade and the degree of its order [24]. These two determinants were reflected in the parametric method of assessing the aesthetics of an object, proposed by Birkhoff [25] and refined by Eysenck [26]. The composition, therefore, has a significant impact on the perception of the aesthetics of the entire building. A key aspect of the study was to isolate the composition as the test item so as to discover pure preferences for themselves.

2.1. Research Questions

1. Is there a relationship between the degree of regularity in facade compositions and aesthetic preferences?
2. Are regular compositions considered more aesthetic than those with a greater degree of irregularity?
3. Is there a relationship between the type of composition and aesthetic preferences?
4. What kind of composition is preferred the most or the least?

2.2. Research Material

Five visualizations of the building's facades were prepared for the study. The limitation of the number of stimuli presented during the study resulted from the processing capacity of the human brain. The maximum number of items stored in working memory is between five and nine [27]. Comparing stimuli (which was the task of the respondents during the study) requires storing them in working memory. Therefore, limiting number of stimuli to five minimized the impact of limited human cognitive abilities on the final test result.

The stimuli were digitally generated to maximize control over their final image. The only variable between the stimuli was the composition of the window openings. The window openings were presented as the simplest and no other elements were placed on the facade, so that, according to the theory of multilayer composition [2], the compositions of many layers doid not overlap and did not affect the perception of the whole. The basis for each of the compositions was the elevation (Figure 2) with dimensions of 16 × 10 m placed on a uniform background, showing a meadow and greenery in the distance. Reducing the building to a flat facade drawing made it possible to eliminate the influence of perspective on the respondents' perception process. Compositions no. 1–5 (Figure 3) were designed as systems of decreasing degree of regularity, with composition no. 1 having the highest and composition no. 5 having the lowest degree of regularity. This effect was achieved through the use of compositions that differed in terms of type of composition elements (one, two or three types of composition elements) and the method of building vertical composition lines. The composition type indicated tentatively with the letter "X" (Figure 4) meant compositions composed of elements stacked on top of each other at equal horizontal distances (the highest degree of regularity). Compositions tentatively marked with the letter "Y" (Figure 5) were compositions consisting of clearly marked compositional verticals (the same elements one above the other), but the distances between the vertical lines were different (average degree of regularity). The composition type, initially marked with the letter "Z" (Figure 6), also had different distances between the compositional verticals; however, additionally, these lines were not built by the elements arranged in accordance with the axis of symmetry one above the other, but by the side edges of these elements (the lowest level of regularity).

Figure 2. The basis for the stimuli for research.

Figure 3. The incentives presented in the study: (**a**) composition no. 1; (**b**) composition no. 2; (**c**) composition no. 3; (**d**) composition no. 4; (**e**) composition no. 5.

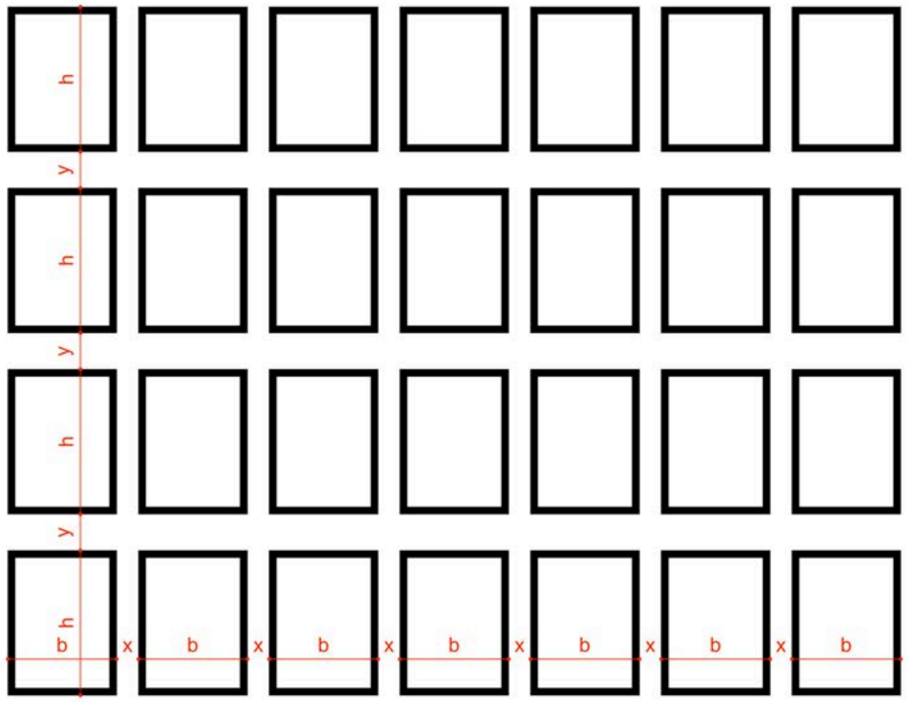

Figure 4. Diagram showing the assumptions of an "X" composition.

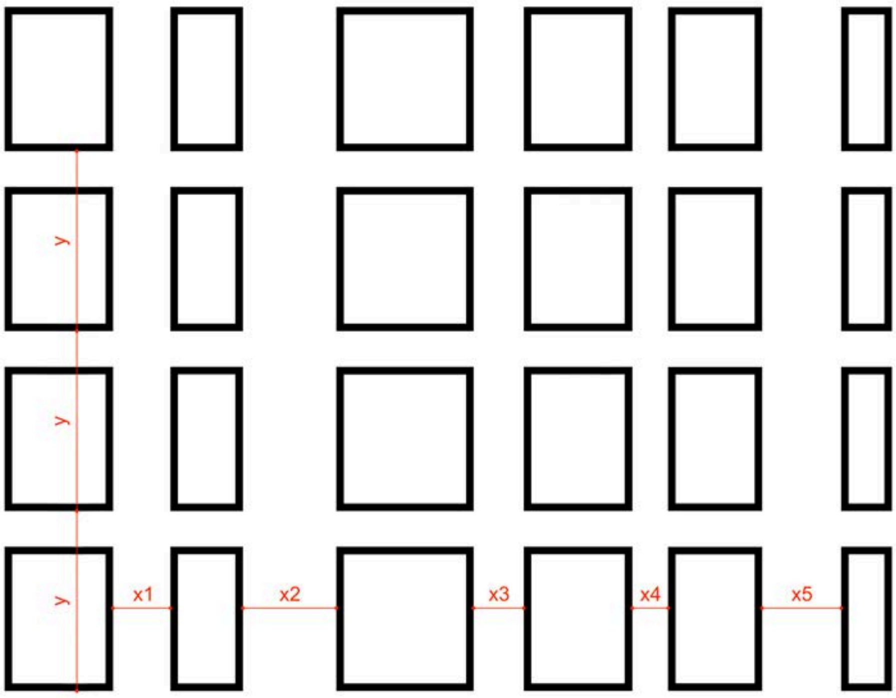

Figure 5. Diagram showing the assumptions of a "Y" composition.

Composition no. 1 (Figure 3a) is the composition of type X with the highest degree of regularity. Composition no. 2 (Figure 3b) is an example of a Y-type composition which differed from the first composition only by the horizontal distances between the window openings and used the same compositional elements. Composition no. 3 (Figure 3c) is also an example of a Y-type composition; however, in this case, different widths of the elements were added, which reduced the degree of regularity of the arrangement with respect to composition no. 2. Composition no. 4 (Figure 3d) is a Z-type composition, based on elements with two different horizontal dimensions. Composition no. 5 (Figure 3e) is also an example of a Z-type composition; however, in this case, elements of three different horizontal dimensions were used. All compositions had 15 elements of equal height arranged in three horizontal lines.

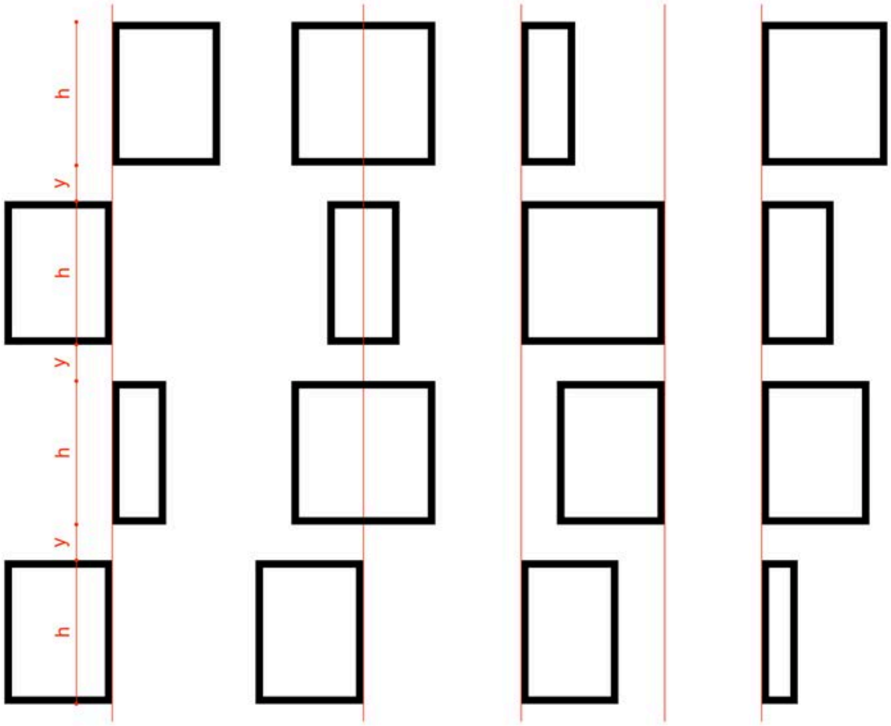

Figure 6. Diagram showing the assumptions of a "Z" composition.

The graphics were prepared on the basis of the original 3D model created in Blender, rendered with the Cycles rendering engine and then processed in Affinity Photo.

2.3. Variables

The following independent variables were introduced into the study: the degree of regularity, defined by a number from 1 to 5, where 1 is the most regular, and 5 the least regular, and the composition type, marked with the letters X, Y and Z (in accordance with the previously described types of compositions). The dependent variable was the degree of aesthetic preference, indicated by a number from 1 to 5, with 1 being the most preferred and 5 being the least preferred.

2.4. Procedure

The performed procedure was based on previous studies [10,28]; however, it used different stimuli, and the rating scale was also limited from 1 to 10 to 1 to 5. On the basis of the prepared research material, an online questionnaire was developed, consisting of two parts. The first part consisted of one task aimed at arranging randomly displayed graphics (described in Section 2.2) from the prettiest (value 1) to the ugliest (value 5). The second part of the questionnaire was not the main element of the study, but it allowed to characterize the research group. This part contained three questions concerning gender, age and education of the respondents, respectively. The survey was conducted from 23 May 2020 to 1 June 2020 and took the form of an online survey. The link to the survey was placed on one of the social networks (Facebook) and shared using a post promotion tool. The message was addressed to people aged 18 to 65 declaring living in Poland.

2.5. Characteristics of the Study Participants

The study involved 109 people (N = 109) and met the statistical guidelines for the minimum survey sample for populations larger than 5000 [29]. Margin of error of the research was at the level of 9%, with a confidence level of 95%. Respondents were aged 18 to 62 (M = 31.18, SD = 11.25), of which 75 were women and 34 were men. In total, 73 people had higher education (66.97%), 28 people secondary (25.68%) and 4 people (3.67%) each had primary and vocational education.

3. Results

3.1. Research Questions 1 and 2

In order to answer research question one, a one-way ANOVA was performed in an intergroup scheme. The dependent variable in these calculations was the degree of regularity (on a scale from one, the most regular, to five, the least regular) to which the presented stimuli belonged. The dependent variable valued the determining aesthetic preferences in relation to stimuli (on a scale from one, the most attractive, to five, the least attractive). A summary of the results obtained during the above-described operation is presented in Table 2.

Table 2. ANOVA summary of the variable "degree of aesthetic preference" depending on the degree of regularity of the composition.

Source	SS	df	MS	F
Between groups	167.76	4	41.94	22.83 **
Inside groups	890.86	485	1.84	
Overall	1058.62	489		

** $p < 0.001$.

The analysis of variance turned out to be statistically significant—F (4.489) = 22.833, $p < 0.001$—, which proved the relationship between the degree of regularity of the composition and aesthetic preferences.

Post hoc tests were performed to see if there were differences in aesthetic preferences depending on the particular composition. The result of Levene's test for the variable "aesthetic preferences" turned out to be statistically significant ($p < 0.001$); hence, the assumption of the equality of variance was rejected and Dunnett's T3 test was used. The analyses showed that there was a statistically significant difference in aesthetic preferences between compositions no. 1 and no. 4 and 5, between compositions no. 2 and no. 4 and 5, and between compositions no. 3 and no. 4 and 5.

The above results, together with the results of the descriptive statistics (Table 3), indicated the existence of two groups of compositions and provided answers to research question two. The first group consisted of compositions with a higher degree of regularity, i.e., no. 1 (M = 2.34; SD = 1.428) , no. 2 (M = 2.45; SD = 1.202) and no. 3 (M = 2.64; SD = 1.270), which did not differ statistically significantly in terms of the degree of aesthetic preferences. The second group consisted of compositions with a lower degree of regularity, i.e., no. 4 (M = 3.62; SD = 1.240) and no. 5 (M = 3.68; SD = 1.596), which also did not differ statistically significantly from each other in terms of the degree of aesthetic preferences. In contrast, the compositions of the first group (i.e., no. 1, 2 and 3) were statistically significantly more preferred than the compositions of the second group (i.e., no. 4 and 5).

The data collected during the survey were also subjected to a statistical correlation analysis. A statistically significant, weak, positive correlation was found between the degree of regularity and the degree of aesthetic preference: r = 0.372; $p = 0.01$. Therefore, the higher the degree of regularity in the composition, the higher the degree of aesthetic preference, which was consistent with the analyses carried out earlier on research question two.

However, attention should be paid to the graph (Figure 7) of the distribution of the frequency of assessments of the degree of aesthetic preference depending on the degree of the regularity of the composition. Although the mean values of the degree of aesthetic preference for the compositions with the degree of regularity 1, 2 and 3 were similar (which was confirmed by the post hoc tests carried out), the response frequency distribution graphs for these compositions clearly differed from each other. Composition no. 1 was significantly more frequently rated as the most aesthetic (37.76% of the response) than compositions no. 2 (21.35% of the response) and no. 3 (16.33% of the response). On the other hand, composition no. 5 was rated as the least visually attractive by 49.49% of the respondents, i.e., 11.73 percentage points more than the most positive grades for composition no. 1. In view of the above, it could be assumed that the irregular compositions elicited negative reactions more strongly than the regular compositions elicited the positive reactions.

Table 3. Descriptive statistics for the dependent variable "Degree of Aesthetic Preference" for composition.

Function	No. 1	No. 2	No. 3	No. 4	No. 5
Standard deviation	1.428	1.202	1.270	1.240	1.596
Standard error	0.144	0.121	0.128	0.125	0.161
The minimum value	2.05	2.21	2.39	3.37	3.36
Mean *	2.34	2.45	2.64	3.62	3.68
The maximum value	2.62	2.69	2.90	3.87	4.00

* Lower value means greater aesthetic preference for a given composition.

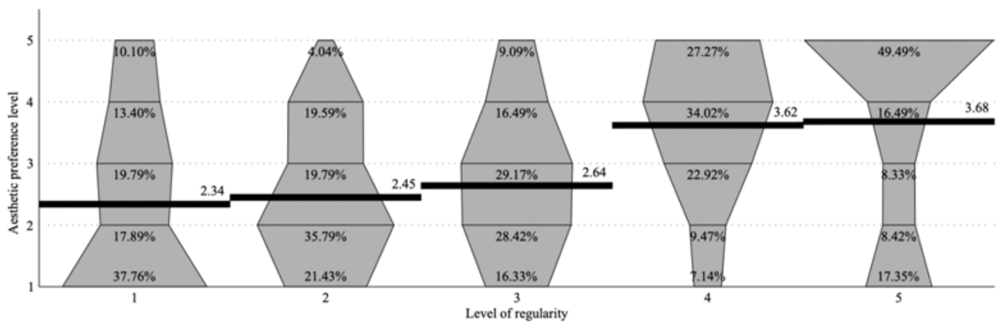

Figure 7. Distribution of aesthetic preferences in relation to the degree of regularity of the facade.

It is also interesting to note that 55.65% of the aesthetic preference score for composition no. 1 was above the average, and for composition no. 2 this was 57.22%. Compositions no. 3, 4 and 5 had more than half of the scores below average, and composition no. 5 had 65.85% of these scores. The above results (presented in Figure 8) meant that regular compositions were more often assessed as the most attractive, while irregular compositions had the opposite effect.

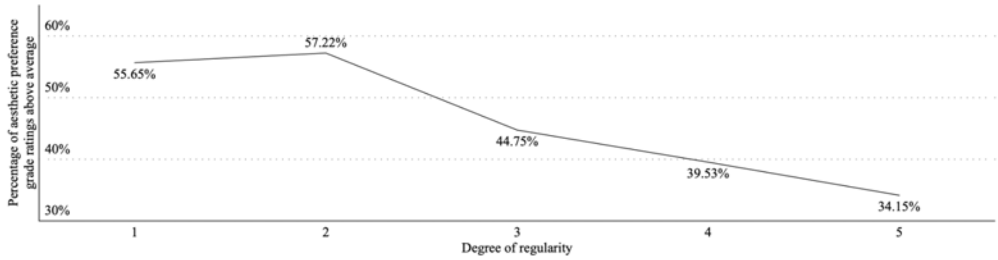

Figure 8. Percentage of aesthetic preference grade above avarage.

The conducted analyses indicated a clear relationship between the degree of regularity in the composition and the degree of aesthetic preference. Although the analyses based on the comparison of means did not prove a linear gradation of correlating variables with each other, the frequency plots showed a different effect. More regular compositions were judged to be more aesthetic than less regular compositions. Equally important is the fact that irregular compositions were assessed as visually unattractive, much more than regular compositions were assessed as attractive. In other words, irregular stimuli elicited a more pronounced effect than regular stimuli.

3.2. Research Questions 3 and 4

In order to answer research question three, a one-way ANOVA was performed in an intergroup design. The dependent variable in these calculations was, the type of composition (marked with the letters X, Y and Z), to which the presented stimuli belonged. Dependent variables valued the determining aesthetic preferences in relation to stimuli (on a scale from one, the most attractive, to five, the least attractive). A summary of the results obtained during the above-described operation is presented in Table 4.

Table 4. ANOVA summary for the variable "degree of aesthetic preference" depending on the type of composition.

Source	SS	df	MS	F
Between groups	165.74	2	82.87	45.199 **
Inside groups	892.88	487	1.83	
Overall	1058.62	489		

** $p < 0.001$.

The analysis of variance turned out to be statistically significant—F (2.489) = 45.199, $p < 0.001$—, which proved the relationship between the type of composition and aesthetic preferences.

Post hoc tests were performed to see if there were differences in aesthetic preferences depending on the particular type of composition. The result of Levene's test for the variable "aesthetic preferences" turned out to be statistically significant ($p < 0.001$); hence, the assumption of the equality of variance was rejected and Dunnett's T3 test was used. The analyses showed that there was a statistically significant difference ($p = 0.05$) in terms of the aesthetic preferences between composition type X and Z, and also between type B and E. The above results combined with the results of descriptive statistics meant that compositions of type X (M = 2.34; SD = 1.428) and Y (M = 2.55; SD = 1.237) were preferred at a similar level. At the same time, these compositions were more preferred than the Z type compositions (M = 3.65; SD = 1.426). Descriptive statistics are presented in Table 5.

Table 5. Descriptive statistics for the dependent variable "Degree of Aesthetic Preference" for composition.

Function	Type X	Type Y	Type Z
Standard deviation	1.428	1.237	1.426
Standard error	0.144	0.088	0.102
The minimum value	2.05	2.37	3.45
Mean *	2.34	2.55	3.65
The maximum value	2.62	2.72	3.85

* Lower value means greater aesthetic preference for a given composition.

One should also pay attention to the data contained in Figures 9 and 10. The distribution of the frequency of the assessments of the degree of aesthetic preference depending on the type of composition showed that although the means for type X and Y were similar (which resulted from the post hoc tests), the compositions of type X were almost twice as likely to be rated most attractive (37.76% of responses) than compositions of type Y (18.88% of responses). Equally important is the fact that only 36.85% of the respondents assessed Z-type compositions above average and, what is even more important, only 21.18% of the respondents assessed such compositions as positive (value one or two). The above results clearly indicate that X-type compositions were perceived as more attractive compared to Y-type compositions, and the compositions of both types clearly dominated (in terms of aesthetic preferences) over Z-type compositions.

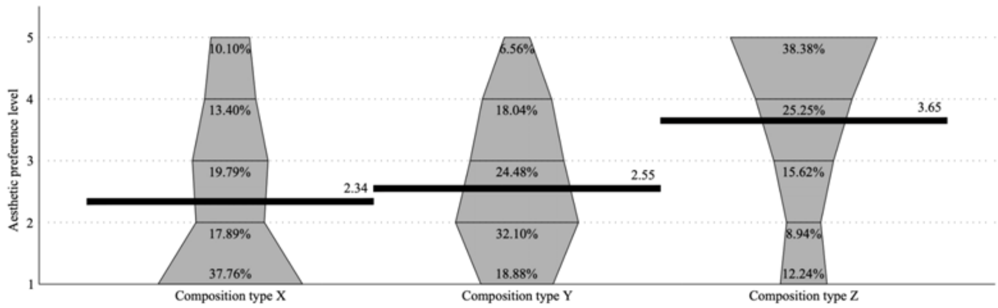

Figure 9. Distribution of aesthetic preferences in relation to the composition type of the facade.

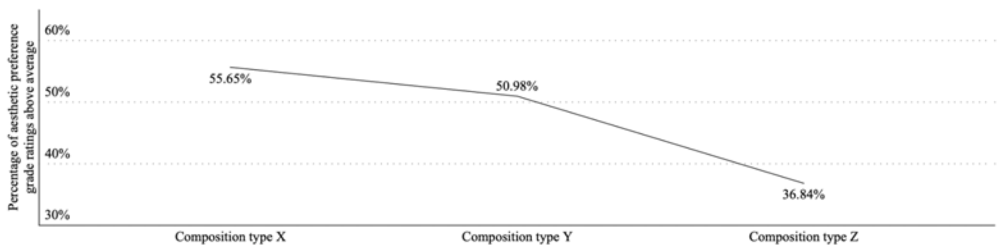

Figure 10. Percentage of aesthetic preference grade above average.

The conducted analyses indicated a clear relationship between the type of composition and the degree of aesthetic preference. Statistics based on averages showed that both the X and Y-type compositions were stated to be more attractive than the Z compositions; however, the differences between X and Y types were statistically insignificant. The analysis of the frequency charts showed, however, that also between types X and Y there were clear differences in the degree of aesthetic preference, where X-type compositions were twice as likely to be the most attractive compared to Y-type compositions.

4. Discussion

The aim of this study was to determine the relationship between the degree of regularity of the composition and the type of composition of the building facade and aesthetic preferences. Therefore, a questionnaire survey was conducted. Statistical analyses of the collected results created the possibly to answer research questions and formulate conclusions.

The results of statistical analyses clearly indicated the relationship between the degree of the regularity of the composition and the aesthetic preferences for these compositions. Although the correlation index indicated a weak relationship between these two variables, further analyses clearly showed that, generally, compositions with a higher degree of regularity were preferred over the less regular ones. Thus, the compositions of the type X and Y were considered more visually attractive than the compositions of the type Z. It could, therefore, be assumed that the key element for the perception of a given facade composition is the legibility of the vertical composition axes. The compositional axes in the case of Z-type compositions were marked less clearly than the arrangement of elements one above the other according to their axis of symmetry, as in the case of X and Y compositions. It also resulted from the Gestalt principles closeness and continuity [30], according to which we perceive compositional elements one above the other as one vertical line. The grouping of elements vertically and not horizontally results from the vertical nature of architecture [31]. This direction is also suggested by the window openings themselves, which usually have the proportions of a vertically arranged rectangle.

However, a question may be raised as to whether the compositional axes themselves or the clarity of the rule according to which a given composition was created were important in this aspect. Naturally, compositions of type X were subject to the greatest number of constraints and were the most ordered; therefore, the readability of these rules was the greatest in this case. Furthermore, the arrangement of elements one above the other according to the axis of symmetry of each of them was the most natural arrangement, and the compositional axes built by the side edges of the elements (as in the case of Z-type compositions) were not so clear and required a longer analysis. The application of compositional rules, however, was closely related to building compositional axes, although not necessarily in the vertical direction. Therefore, it may not be possible to investigate the correlation between the clarity of a compositional rule and aesthetic preferences in isolating the compositional axes from readability. The results of such analyses would certainly be very interesting and would broaden the knowledge of the perception of composition.

5. Conclusions

The results of the study are in line with previous reports on abstract patterns [11–15]. Facades with a regular composition were found more aesthetic than those with an irregular composition. However, the most important for shaping architecture is the effect associated with the negative impact of irregularity, which was clearly stronger than the positive impact of regularity. Such results suggest the need to explore the subject of composition, especially in the context of the perception of irregular compositions (e.g., “Z” type), as it may turn out that they are definitely considered visually unattractive. On the other hand, the conscious use of compositional irregularity may be a desirable visual reinforcement for a dominant or other significant object.

Nevertheless, in the opinion of the authors, formulating general guidelines for designers and architects on the basis of this study would be too hasty. The conducted research should be treated as a starting point for further analyses, deepening the subject of the perception of compositions. First of all, attention should be paid to the problem of the scale of the building. It may turn out that, in the case of larger buildings, regular compositions would not be the most frequently chosen, which would be consistent with the reports of videoecology [16,17]. Relating the research to larger facades would also involve the analysis of compositions consisting of a greater number of elements and would also allow the creation of systems with more subtle differences in the degree of regularity.

Subsequent research should also take into account the influence of other architectural elements on composition preferences. It may turn out that different surroundings, a different colour or material of the façade, different shapes of windows or forms of roofs or the shape of the façade itself would result in a change in preferences regarding the composition.

Another important issue is the multilayer composition theory [2] and the influence of the composition of individual layers on the preference for the composition of the whole. Certainly, the way the stimulus is presented is also important. It would be interesting to see the results of research carried out on the basis of visualizations of buildings from the human perspective. Furthermore, the use of technologies, such as VR, could provide interesting results and would make it possible to arrange a virtual walk; thus, bringing the perception processes occurring during the study closer to those that appear under normal conditions.

This study, in the opinion of the authors, also indicated a very important feature of the composition, which is the degree of regularity. Not only preferences, but also the perception of the degree of regularity in the composition should be the subject of separate research. The results of such analyses could allow for a more conscious design, as they would give designers an understanding of what reactions and perceptions are generated by specific aesthetic treatments.

Author Contributions: Conceptualization, M.M. and P.C.; methodology, M.M.; software, M.M.; validation, A.T. and P.C.; formal analysis, M.M and P.C.; investigation, M.M.; resources, M.M.; data curation, M.M.; writing—original draft preparation and editing, M.M.; writing—review, A.T. and P.C.; supervision, A.T. and P.C.; project administration, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: The consent of the participants was disregarded because the participation in the study was anonymous and voluntary and the questionnaire did not concern sensitive data concerning the participants of the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Alexander, C. *A Pattern Language: Towns, Buildings, Construction*; Oxford University Press: Oxford, UK, 1977.
2. Tayyebi, S.F., Demir, Y. Architectural Composition: A Systematic Method to Define a List of Visual Attributes. *Art Des. Rev.* **2019**, *7*, 131–144.
3. Brielmann, A.A.; Pelli, D.G. Aesthetics. *Curr. Biol.* **2018**, *28*, R859–R863, doi:https://doi.org/10.1016/j.cub.2018.06.004.
4. Sartwell, C. Aesthetics of the Everyday. In *The Oxford Handbook of Aesthetics*; Levinson, J., Ed.; Oxford University Press: Oxford, UK, 2005.
5. Fukasawa, N.; Morrison, J. *Super Normal: Sensations of the Ordinary*; Lars Muller: Baden, Switzerland, 2007.
6. Scrouton, R. *The Aesthetics of Architecture*, Revised ed.; Princeton University Press: Princeton, NJ, USA, 2013.
7. Harris, S. *Architecture of the Everyday*; Princeton Architectural Press: Princeton, NJ, USA, 1998.
8. Dyckhoff, T. *The Age of Spectacle*; Cornerstone Digital: New York, NY, USA, 2017.
9. Till, J. *Architecture Depends*; MIT Press: Cambridge, MA, USA, 2009.
10. Safarova, K.E.A. Differences between young architects' and non-architects' aesthetic evaluation of buildings. *Front. Archit. Res.* **2019**, *8*, 229–237, doi:10.1016/j.foar.2019.04.001.
11. Pecchinenda, A.; Bertamini, M.; Makin, A.D.J.; Ruta, N. The Pleasantness of Visual Symmetry: Always, Never or Sometimes. *PLoS ONE* **2014**, *9*, e92685, doi:10.1371/journal.pone.0092685.
12. Taylor, R.;Newell, B.; Spehar, B.; Clifford, C. Fractals: A Resonance between Art and Nature. In *Mathematics and Culture II*; Emmer, M., Ed.; Springer: Berlin, Germany, 2005; pp. 53–63, doi:10.1007/3-540-26443-4_6.
13. Taylor, R. Fractal Expressionism-Where Art Meets Science. In *Art and Complexity*; Casti, J., Karlqvist, A., Eds.; JAI: Atlanta, GA, USA, 2003.
14. Friedenberg, J.E.A. Judged Beauty of Fractal Symmetries. *Empir. Stud. Arts* **2021**, *40*, 027623742199469.

15. Bertamini, M.; Makin, A.; Rampone, G. Implicit Association of Symmetry with Positive Valence, High Arousal and Simplicity. *I Perception* **2013**, *4*, 317–327, doi:10.1068/i0601JW.
16. Filin, V.A. *Videoecologiya*; TASS-Reclama: Moscow, Russia, 1997.
17. Wilkins, A.J. *Visual Stress*; Oxford University Press: Oxford, UK, 1995.
18. Stamps, A. Entropy, Visual Diversity, and Preference. *J. Gen. Psychol.* **2002**, *129*, 300–320.
19. Zeki, S. *Inner Vision: An Exploration of Art and the Brain*; Oxford University Press: Oxford, UK, 1999.
20. Vartanian, O.; Goel, V. Neuroanatomical correlates of aesthetic preference of paintings. *Neuroreport* **2004**, *15*, 893–897, doi:10.1097/00001756-200404090-00032.
21. Kawabata, H.; Zeki, S. Neural correlates of beauty. *J. Neurophysiol.* **2004**, *91*, 1699–1705.
22. Cela-Conde, C.J.; Marty, G.; Maestú, F.; Ortiz, T.; Munar, E.; Fernández, A.; Roca, M.; Rosselló, J.; Quesney, F. Activation of the prefrontal cortex in the human visual aesthetic perception. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 6321–6325.
23. Markiewicz, P. Neuroaesthetics-Critical Analysis of Selected Empirical Studies. *Humanistyka I Przyrodoznawstwo* **2009**, *15*, 113–123.
24. Meddahi, K.; Boussora, K. Aesthetic Measures of Algiers' Colonial Facades. *Nexus Netw. J.* **2021**, *23*, 667–688.
25. Davis, R.C. An Evaluation and Test of Birkhoff's Aesthetic Measure Formula. *J. Gen. Psychol.* **1936**, *15*, 231–240.
26. Eysenck, H.J. The Empirical Determination of an Aesthetic Formula. *Psychol. Rev.* **1941**, *48*, 83–92.
27. Miller, G.A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychol. Rev.* **1956**, *63*, 81.
28. Graham, B.; Gifford, R. Architects predicts lay evaluations of large contemporary buildings: Whose conceptual properties? *J. Environ. Psychol.* **2001**, *21*, 93–99, doi:https://doi.org/10.1006/jevp.2000.0176.
29. Mundfrom, D.J.; Shaw, D.G.; Ke, T.L. Minimum Sample Size Recommendations for Conducting Factor Analyses. *Int. J. Test.* **2005**, *5*, 159–168.
30. Wertheimer, M. Untersuchungen zur Lehre von der Gestalt. II. *Psychol. Forsch.* **1923**, *4*, 301–350, doi:10.1007/BF00410640.
31. Arnheim, R.; *The Dynamics of Architectural Form*; University of California Press: Berkeley, CA, USA, 1977.

4.5 PUBLIKACJA V

Nexus Network Journal
https://doi.org/10.1007/s00004-025-00827-x

RESEARCH

The Mathematical Regularity Coefficient for Facade Patterns

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Accepted: 13 May 2025

Abstract
This article investigates whether the visual regularity of a building's facade can objectively be expressed by a numerical value. Grounded in universal neurobiological principles and modern digital image processing methods from mathematical and information theories, this study analyzes 245 architectural compositions using an interdisciplinary approach that combines perception, mathematics, programming, and architectural theory. A coefficient was derived with an almost ideal average correlation to regularity and minimal variability. Building on these findings, an open-source computer tool was developed to measure the regularity of flat architectural compositions. These results enhance our understanding of compositional perception and support the development of advanced architectural design tools, including generative algorithms.

Keywords Visual regularity · Architectural composition · Digital design tools · Information theory · Perception · Algorithms

Introduction

This paper investigates the development of a method to measure the consistency of patterns on the exterior of buildings. According to Krier (1992), the correct arrangement of parts is crucial to designing visually appealing and balanced architecture. Combining architectural elements emphasize order, hierarchy, proportion, and rhythm. According to the theory of Birkhoff and Eysenck (Davis 1936; Eysenck 1941), the aesthetics (not only) of architectural works culminates from the right balance between complexity and regularity. This paper discusses the regularity of pat-

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Published online: 26 May 2025

terns, focusing on the arrangement of elements such as windows and balconies on façades.

The following research questions guide the work based on the identified research challenges. First, can a mathematical coefficient be defined as one that objectively quantifies the visual regularity of façade patterns? Second, to what extent does this coefficient correlate with the perceived visual regularity observed in different façade pattern types?

This study hypothesizes the existence of a mathematical coefficient that strongly correlates with the visual regularity of façade patterns. This assumption draws on universal biological principles governing the perception of regularity (Amir et al. 2011; Biederman 1987; Kayaert et al. 2005; Kubilius et al. 2014). As a result, visual regularity appears objective and tends to be perceived similarly across human observers (Malewczyk et al. 2022, 2024). Numerous image analysis studies employing entropy-based approaches (Crompton 2012; Grebekina et al. 2018; Güzelci et al. 2021; Güzelci & Alaçam 2019; Güzelci et al. 2020; Redies et al. 2017; Stamps 2004, 2012, 2014; Stanischewski et al. 2020) further support the notion that visual regularity constitutes a quantifiable phenomenon.

If the hypothesis proves valid, a secondary objective involves verifying previous experimental findings, which demonstrated a correlation between the perceived regularity of façade compositions and their respective pattern types (Malewczyk et al. 2022, 2024). The current study adopts a markedly different methodological framework. Despite this divergence, the results align with earlier observations and provide additional support for the previously established correlation.

Assuming the research hypothesis is confirmed, this study proposes the development of an open-source computational tool capable of objectively assessing the regularity coefficient of façade patterns. The scope of the research reaches beyond the field of architecture, drawing from contemporary computational technologies, mathematical statistics, information theory, and architectural theory. By integrating these disciplines, the study addresses fundamental issues related to visual regularity, perceptual principles, and current methodologies for analyzing image structure and façade compositions (Malewczyk et al. 2022, 2024). In the subsequent section, these topics are further elaborated upon.

Related terms

Visual Regularity and Its Perception

Kubilius, Wagemans, and Op de Beeck (2014) demonstrated a linear relationship between neural responses in specific brain regions and the regularity of visual stimuli. This linear neural reaction appears consistent across individuals, suggesting that the entire mechanism of visual regularity perception operates universally in humans. Biederman (1987), Kayaert et al. (2005), and Amir et al. (2011) found that regular stimuli activate particular areas of the brain, while irregular stimuli do not. Arnheim's (1977) behavioral research further supports above mentioned conclusion. Consequently, a mathematical indicator of compositional regularity may be an objective measure of perceivable regularity.

Gestalt principles classify a structure as regular when it exhibits a systematic arrangement of objects (Koffka, 1935). According to Wagemans et al. (2005), order emerges from specific governing laws that synergistically influence perception. Arnheim (1977) further conceptualized regularity as a tension-free state of equilibrium, typically underpinned by symmetry in visual arts and architecture, whereas disordered states lack such organizing principles. Pironio (2018) characterizes irregularity as the absence of predictable patterns and positions regularity as its antithesis.

Consistent with these theoretical frameworks, empirical studies in psychology and experimental aesthetics confirm that visual structures perceived as regular are subject to universal laws. Investigations have addressed the impact of environmental context on regularity perception (Sun et al., 2019) and the relationship between bilateral symmetry and aesthetic preference (Pecchinenda 2014; Friedenberg 2021; Bertamini et al. 2013). Furthermore, Katkov et al. (2015) demonstrated that the human brain organizes abstract stimuli according to principles akin to those in statistical mechanics. Observers classify compositions featuring uniform elements and consistent spacing as regular, while they view compositions with variable elements and spacing as more random.

Similar conclusions can be drawn from the experiment by Malewczyk et al. (2024), which proves the relationship between the perceived regularity of the composition and the type of composition pattern (Malewczyk et al. 2022). This typology, which defines six pattern types (labeled A–F), originates from an analysis of 113 housing developments. Figure 1 illustrates the general principles defining each type and reveals their fundamental differences in arranging the compositional elements on the façade's plane. The analysis revealed a strong relationship (68.6%) between regularity and pattern type. An experimental study with human participants (Malewczyk et al. 2024) empirically established the relationship.

Methods of Image Regularity Analysis

Methodologies for assessing the regularity of visual stimuli and generating images with controlled irregularity are examined. One commonly used technique involves applying random perturbations—jittering—to a regular image, with the level of irregularity scaling with the magnitude of the perturbations (Sun et al. 2019). Researchers have extensively explored the assessment of pattern regularity in the field of image encryption, where they evaluate algorithm performance using measures such as global Shannon entropy, histogram analysis, differential cryptanalysis, and pixel correlation (Li et al. 2017; Xu et al. 2016; Belazi et al. 2016; Benoit et al. 2014). Among these measures, Shannon entropy proves particularly relevant to the present study.

In 19th-century thermodynamics, scientists introduced entropy to quantify a system's disorder. In 1948, Claude Shannon redefined it. Shannon established a link between entropy and information, defining it as the average amount of information per message.

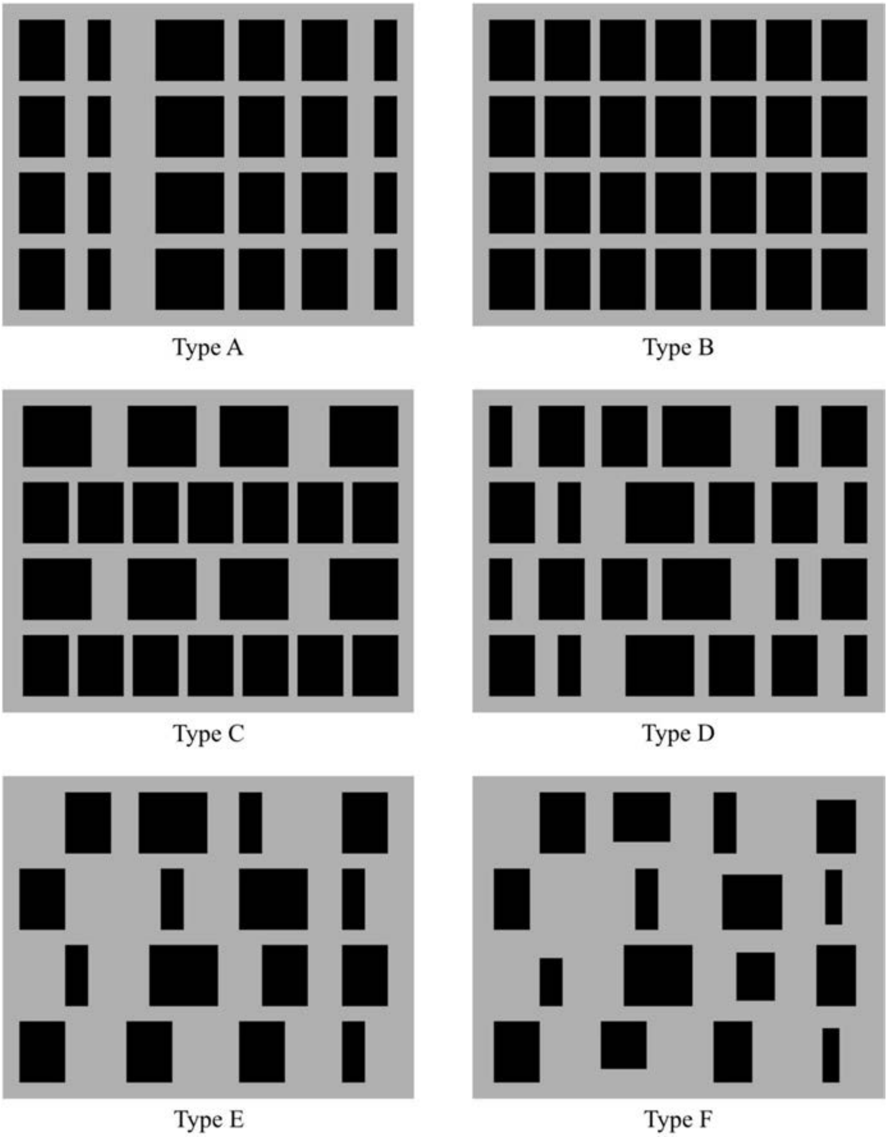

Fig. 1 Examples of façade patterns (compositions) classified according to the typology. Image: Malewczyk et al. 2022

$$H = -\sum_{i=1}^{n} p_i log_2 p_i$$

Formula 1. Entropy in information theory

According to Formula 1, entropy in information theory (Shannon entropy) depends on the frequency of identical information or values in the whole string. In the 5-element sequence 'AECBD' each of the letters appears once in this 5-element string, so the probability of each of them appearing is 0.2; therefore:

$$H = 5x0.2\log_2 0.2 = 2.32193$$

The invariance of a sequence's entropy with respect 'ABCDE,' 'EDCBA,' and 'ACBDE' yield identical entropy values. Only the distinctiveness of the symbols, not their diversity, influences the measure– hence, sequences such as 'AZMPT,' '12,345,' or '17,290' share the same entropy as 'AECBD'. Moreover, because entropy increases with string length, metric entropy– the entropy (H) divided by the string length– facilitates comparisons across sequences.

Redies et al. (2017) propose that edge orientation entropy differentiates domains of human creativity, noting that Western paintings have lower entropy than East Asian or Islamic art. Stanischewski et al. (2020) found a positive correlation between aesthetic preference for abstract linear patterns and edge orientation entropy, while Grebekina et al. (2018) observed similar patterns in linear designs, abstract textures, album covers, and architectural photographs. Stamps (2004) also demonstrated that perceived diversity in the built environment correlates with entropy.

Although researchers widely apply Shannon's entropy in studies of the built environment (e.g., Güzelci et al. 2021; Güzelci & Alaçam 2019; Güzelci et al. 2020; Crompton 2012; Stamps 2012, 2014), most of these studies rely on the global entropy index, which fails to account for spatial rearrangements of elements—a critical aspect in compositional analysis. In contrast, Wu et al. (2013) introduced a statistical test based on Shannon's local entropy that computes the standard deviation of local entropy values from randomly sampled regions, thereby capturing variations in element positioning.

Materials and Method

Materials

All photos used as research material depict residential, multi-family buildings nominated for the 2024 European Union Prize for Contemporary Architecture– Mies van der Rohe Award (EU Mies Award 2024) and classified as 'collective housing.' All photographs were obtained from the award organizer's archive (https://miesarch.com/archive). Randomly selected projects are presented in Fig. 2.

Given that a nomination for this award affirms an object's quality, the study selected buildings based on this criterion, assuming they represent a typical sample of contemporary European multi-family residential architecture.

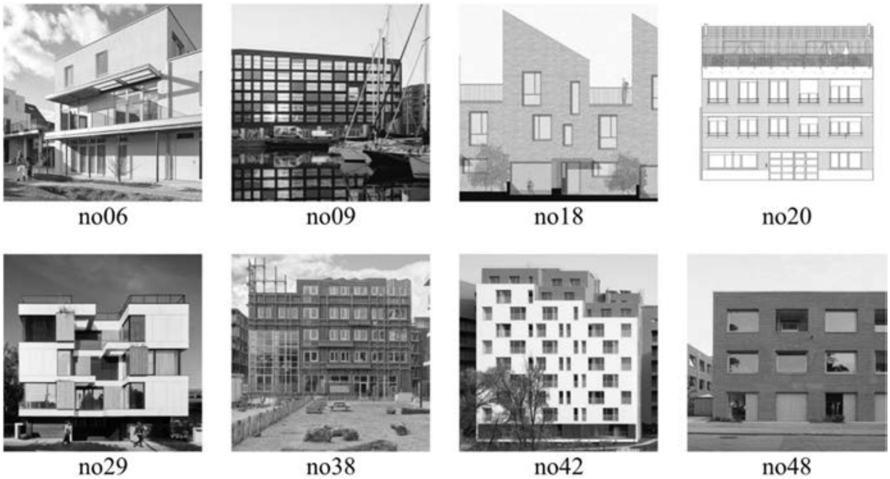

Fig. 2 Selection of architectural projects from the group of 49 chosen for the survey

Methods

Shannon Entropy and Classical Variability Measures

Stamps (2004, 2014) calculated entropy from information sequences derived via semantic analysis of architectural façades– a method similarly employed by Crompton (2012) and Güzelci (2019, 2021). Stanischewski et al. (2020) further analyzed the entropy of rotation angles of straight lines in images.

Building on these studies, this research introduces an innovative method that recodes input data from photographs and façade drawings by transforming compositional formulas into sequences of element dimensions and inter-element distances. Subsequent analyses and calculations are performed on these sequences, incorporating classical variability measures such as mean, variance, standard deviation, and coefficient of variation. Figure 3 summarizes the entire procedure of the study.

Software

The study primarily employed Blender version 4.2.1 for MacOS to create compositional objects using its 3D modeling tools and an integrated text editor for running Python 3.12 scripts. The script imports libraries such as bpy, CSV, math, math utils, collections, and datetime. Microsoft Excel version 16.87 for MacOS was used to process the raw data, conduct statistical analyses, and generate the final results.

Creating compositions

The study's first phase involved creating the research compositions. Fifty photographs of buildings nominated for the EU Mies Award 2024 in the 'collective housing' category were imported into Blender, then 49 two-dimensional compositions

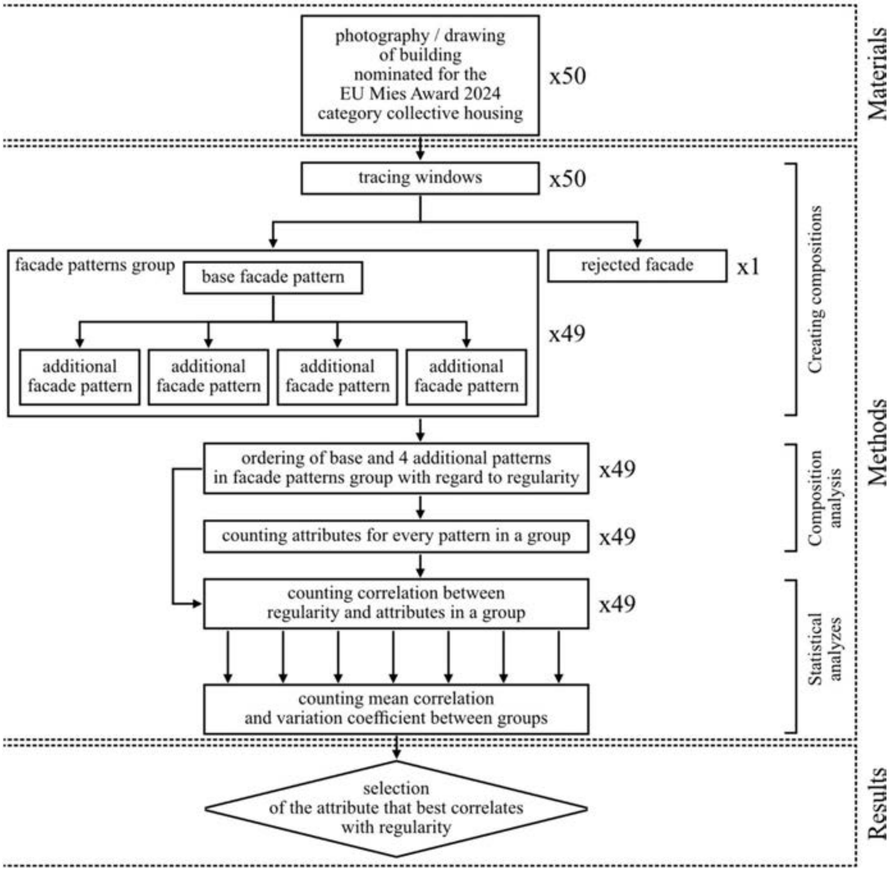

Fig. 3 Flowchart summarizing the study procedure

were generated. Each composition, representing window arrangements as rectangles on the XY plane, faithfully reproduced the window layout for orthogonal images and their approximation for perspective photos. One building—the 'Kiubo' by Hofrichter-Ritter Architekten, Graz was excluded, as its replication proved challenging.

Subsequently, the study derived four variants from each composition by systematically modifying vertical and horizontal diversification, element displacement, and bilateral symmetry, while also incorporating random perturbations or alignments. Guided by an established typology and prior research (Malewczyk et al. 2022), this process yielded 49 groups of five compositions each, totaling 245, all maintained at consistent proportions to facilitate statistical comparison.

Figure 4 illustrates the process using architectural project no. 12– a residential complex in Ljubljana by Dekleva Gregorič Architects. A photograph from https://miesarch.com/archive extracted window elements rendered as a two-dimensional composition (code no12.001). Two additional variants were generated: composition no12.002 exhibited enhanced regularity with evenly distributed, straight columns, while composition no12.003 showed reduced regularity due to increased offsets and

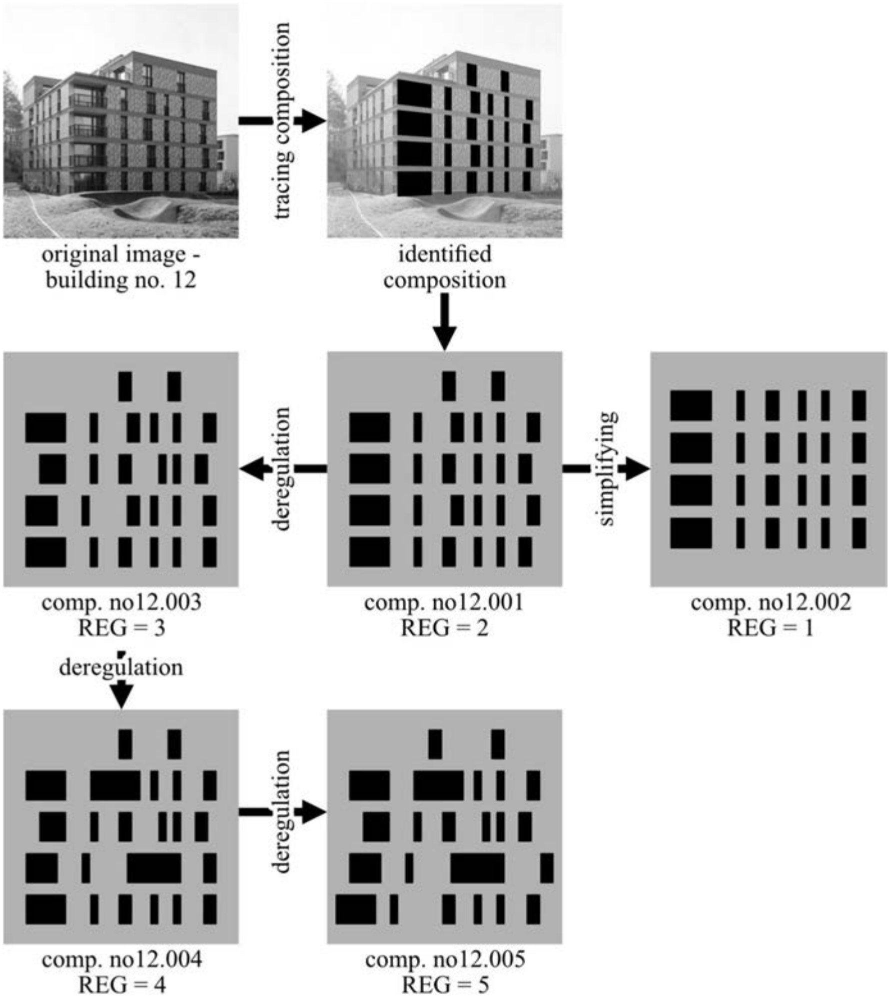

Fig. 4 Protocol for creating research material on exemplary building no. 12

variability in element widths. By systematically increasing irregularity, two further compositions were produced (no12.004 and no12.005). In this series, the original composition (no12.001) was ranked as second in regularity (REG = 2) and REG values were assigned to the other projects based on their derivative compositions.

Composition analysis

During composition process, two values were systematically assigned to each composition in advance and recorded them in a spreadsheet:

- REG is a regularity coefficient on a scale from 1 to 5, where 1 means the most regular and five is the least regular. The coefficient was determined for each composition individually, concerning the other four compositions in each group, based on the number of variables—diversification of elements, diversification of shifts of components with each other, symmetry, and others.

- TYPE– a coefficient determining the type of composition, according to the typology of compositions developed by Malewczyk et al. (2022), where one is type'A', 2–'B', 3–'C', 4–'D', 5–'E' and 6–'F'.

A Python 3 script was developed and executed within Blender's integrated interpreter to process the research material. The script performs mathematical analyses using the vertex coordinates of orthogonal compositional elements (FACES) within each MESH object.

First, the essential mathematical functions were defined and used: arithmetic mean (M), standard deviation (SD), variance (var), and coefficient of variation (V). We also defined a function to calculate the metric entropy. Next, all parameters were derived from the information of individual compositional elements (FACES) in each composition (MESH object) (Table 1).

In the next step, the script calculates the coefficients of variation (V), the metric entropy (H), and the products for the individual parameters. Finally, the script determines 30 values (hereinafter referred to as attributes) for each of the compositions (MESH object). These are: $V(x_{coord})$, $H(x_{coord})$, $V(y_{coord})$, $H(y_{coord})$, $V(x_{coord})$ x $V(y_{coord})$, $H(x_{coord})$ x $(H(y_{coord})$, $V(x_{size})$, $H(x_{size})$, $V(y_{size})$, $H(y_{size})$, $V(x_{size})$ x $V(y_{size})$, $H(x_{size})$ x $H(y_{size})$, V(area), H(area), $V(x_{sidedist})$, $H(x_{sidedist})$, $V(y_{sidedist})$, $H(y_{sidedist})$, $V(x_{sidedist})$ x $V(y_{sidedist})$, $H(x_{sidedist})$ x $H(y_{sidedist})$, V(centerdist), H(centerdist), $V(x_{centerdist})$, $H(x_{centerdist})$, $V(y_{centerdist})$, $H(y_{centerdist})$, $V(x_{centerdist})$ x $V(y_{centerdist})$, $H(x_{centerdist})$ x $H(y_{centerdist})$, $V(centerdist_{ang})$, $H(centerdist_{ang})$.

Statistical analyzes

Statistical analyses were performed in Microsoft Excel by calculating Pearson's correlation coefficient (r) for each of the 49 five-element composition groups. 31 r values for each group were determined– one between the REG coefficient and TYPE and 30 between REG and the other attributes from the Blender script. In addition, the p-value (based on the two-sided Student's T-distribution) was computed for each r, yielding 49 r and p values per attribute and for TYPE.

Subsequently, the arithmetic mean (M) and variation (V) of r for the 30 attributes and the TYPE coefficient was calculated. The number of r values that were highly statistically significant ($p < 0.001$), statistically significant ($p < 0.05$), and insignificant ($p > 0.05$) was also determined.

Research Quality Control and Its Replication

The script was enhanced to visualize connections for the centerdist, $x_{sidedist}$, and $y_{sidedist}$ parameters, verifying the study's results. Three additional objects were created for each of the three compositions, each containing segments that connect the corresponding points. Figure 5 shows the visualization for composition no21.003.

Table 1 Proprietary parameters calculated for the composition

Parameter	Description
x_{coord}	Information about the coordinates of the vertices of individual rectangles on the horizontal x-axis
y_{coord}	Information about the coordinates of the vertices of individual rectangles on the vertical axis– y
x_{size}	Width of the individual rectangles
y_{size}	Height of the individual rectangles
area	Field of individual rectangles
centerdist	The absolute distance between the nearest compositional elements, determined in the following steps of the script: Determination of connections between the centers of all elements of a given composition using the greedy method (each with each) Removal of duplicates—overlapping connections Selection of the shortest connection for a given element in a given quadrant rotated by 45^{O} (one element can be connected to a maximum of four other closest elements– on the right, left, above, and below– as a result of the nature of architectural objects)
$x_{centerdist}$	Distance between the nearest composing elements, measured following the horizontal axis (x) based on the centerdist parameter
$y_{centerdist}$	Distance between the nearest composing elements, measured by the direction of the vertical axis (y), based on the centerdist parameter
$centerdist_{ang}$	inclination angle of straight lines connecting the nearest compositional elements, determined based on the arcus tangent function
$x_{sidedist}$	horizontal distance between the two closest vertical edges of two equal rectangles, determined in the following steps of the script: Calculation of the center points of the vertical edges, left and right, respectively Creating a list of candidate connections using the greedy method (each with each), connecting each right midpoint with each left midpoint Filtering the list by removing segments where the smaller'x' coordinate of a given connection lies on the left side (removing connections that cross the rectangles) and removing duplicates Selection of the shortest connection for a given center point Final verification that a given center point is used no more than once
$y_{sidedist}$	The script determines the vertical distance between the two closest horizontal edges of two equal rectangles in the same way as the $\mathbf{x_{sidedist}}$ parameter

Additionally, vertex coordinate data was exported for individual compositional elements from five randomly selected compositions. The parameters computed by the Blender script were recalculated in Microsoft Excel and compared these results to confirm the script's accuracy.

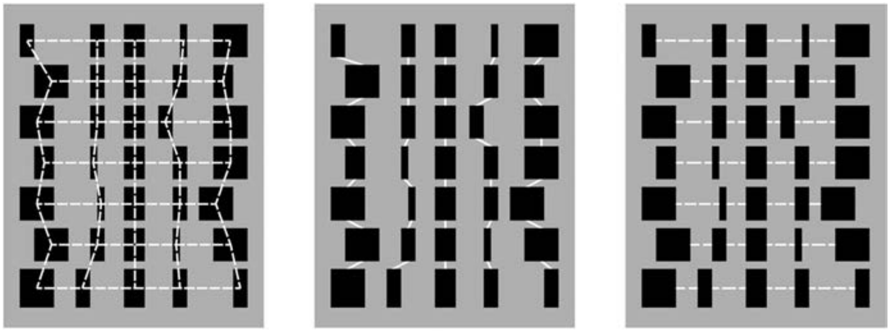

Fig. 5 Visualization of parameters using composition no. 21.003 as an example: **a** centerdist, **b** $y_{sidedist}$, **c** $x_{sidedist}$

The experiment was repeated three times using identical input parameters and environmental configurations to verify reproducibility. The results fully matched, confirming the method's stability and repeatability. All scripts and configuration files are publicly available (https://doi.org/https://doi.org/10.34808/bemn-rd97), allowing independent replication. The same repository that contains the materials required to replicate the experiment also includes a Blender add-on, developed from the original script used to calculate the 30 attributes analysed in this study.

Results

Regularity and Composition of Mathematical Attributes

Under the procedure described in the'Materials and method' section, statistical analyses were carried out based on the collected data for each of the 245 compositions—the values of 30 attributes calculated by the script and the level of regularity—REG. Figure 6 shows the summarization of these results.

For the five attributes, it means $H(y_{sidedist})$, $H(x_{centerdist})$, $H(y_{centerdist})$, $H(x_{centerdist})$ x $H(y_{centerdist})$ and $H(c_{enterdist})$ the average Pearson correlation coefficient (with regularity– REG)– Mr, calculated based on 49 correlation coefficients, corresponding to 49 composition groups, is between 0.9308 and 0.9352 with a variability– Vr– of 7.08 to 9.75%. As mentioned, the results mean a robust correlation with very low volatility. At the same time, in this group of attributes, between 31 and 32 correlations proved to be statistically significant ($p<0.05$) and from 7 to 9– very statistically significant ($p<0.001$). The calculations' average statistical significance level for the r coefficient—Mp—is between 0.0260 and 0.0346.

For the two attributes, it means $H(x_{sidedist})$ x $H(y_{sidedist})$ and $H(centerdist_{ang})$, and the average correlation (with regularity– REG) is also very strong (Mr 0.9063 and 0.9137, respectively). However, their variability is slightly higher– Vr 21.61% and 15.13% respectively. For the attribute $H(x_{sidedist})$ x $H(y_{sidedist})$, the correlation coefficient – r turned out to be statistically significant ($p<0.05$) for 35 and highly statisti-

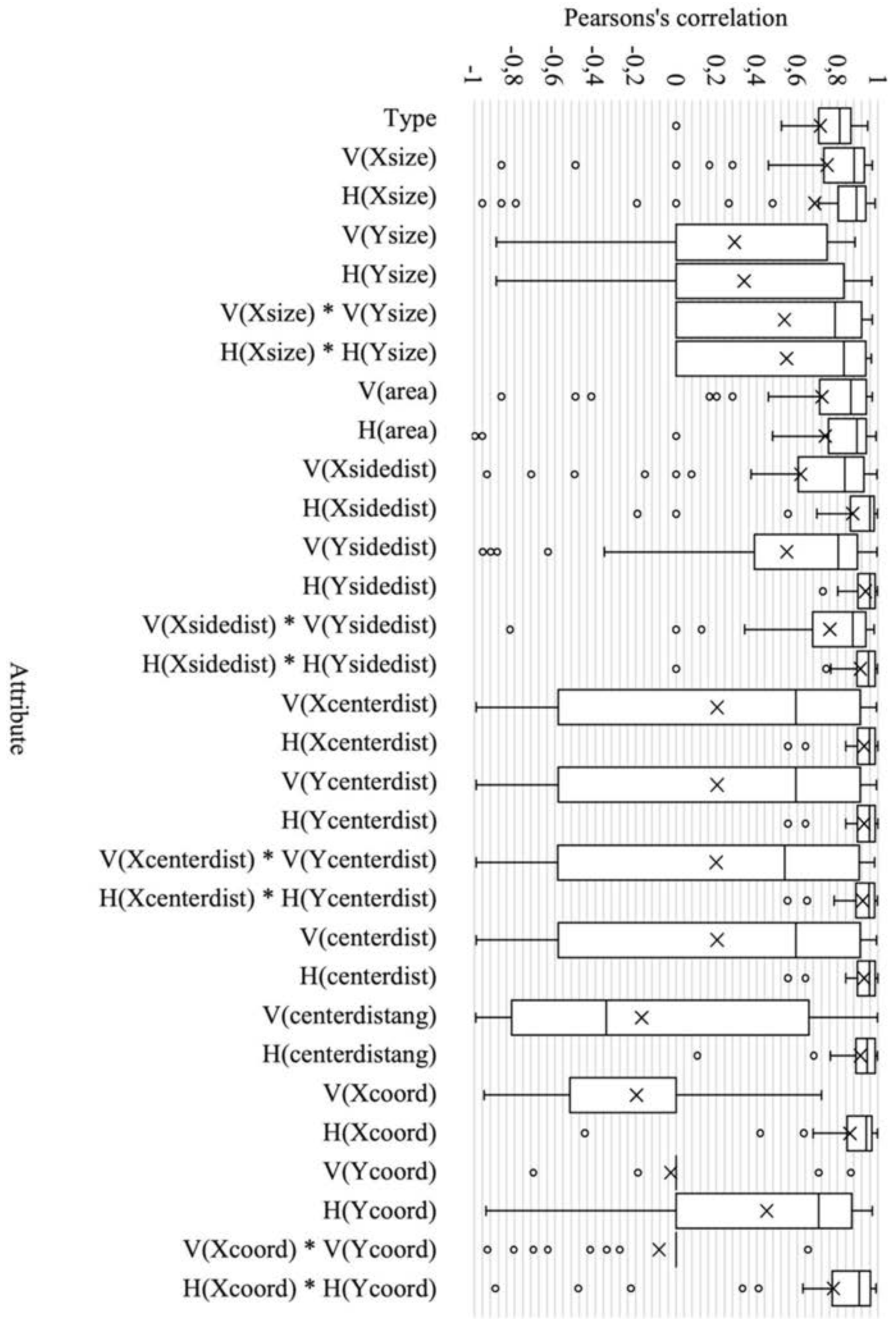

Fig. 6 Boxplot showing composition attributes by Pearson's correlation r-coefficient with composition regularity

cally significant ($p < 0.001$) for 6, with an average statistical significance level of Mp equal to. 0384. Concerning H($centerdist_{ang}$), $p < 0.05$ for 31 r, $p < 0.001$ for 7 r, while the average statistical significance of the r calculations is $Mp = 0.0464$.

Seven attributes showed a strong average correlation (with regularity—REG)—Mr coefficients ranging from 0.7095 to 0.868. H($x_{sidedist}$) and H(x_{coord}) exhibit average variability, with Vr values of 29.65% and 27.47%, respectively. The other five attributes in this group of parameters, mean V(x_{size}), V(area), H(area), V($x_{sidedist}$) x V($y_{sidedist}$), and H(x_{coord}) x H(y_{coord}), are characterized by substantial variability. Vr in the range from 48.10% to 63.31%. The average level of statistical significance $Mp > 0.05$– results of calculating the correlation coefficient– r– statistically insignificant on average.

The following five attributes– H(x_{size}), V(x_{size}) x V(y_{size}), H(x_{size}) x H(y_{size}), V($\mathbf{x_{sidedist}}$), and V($\mathbf{y_{sidedist}}$) show a moderate correlation (with regularity– REG) with Mr at a level of 0.4374 to. 5627. However, the variability of the correlation coefficient for these attributes is substantial—Vr from 78.81% to 102.74%. The correlation coefficient—r—in this group is, on average, statistically insignificant ($Mp > 0.05$).

The average level of correlation of the other 11 attributes with the regularity of composition (REG) is weak (H(y_{coord})—$Mr = 0.4498$ and H(y_{size})—$Mr = 0.3369$), and there is not even a linear relationship ($Mr < 0.2$). The variability of the correlation coefficient—r in this group of attributes is extreme and oscillates between 127.89% and up to 1290.31%. The average statistical significance for these 11 attributes is $Mp > 0.05$—results are statistically insignificant on average.

Regularity and Façade Pattern Type Correlation

To verify the relationship between composition type (TYPE), as defined by Malewczyk et al. (2022), and composition regularity (REG), the study calculated correlations for each of the 49 five-element groups. Although the average correlation was strong ($Mr = 0.7145$, $Vr = 36.31\%$), only 6 out of 49 cases achieved significance ($p < 0.05$), and the average p-value ($Mp = 0.2050$) did not indicate statistical significance.

Blender Add-on to Determine the Regularity of the Composition

Building on the original script– which computed 30 attributes per composition and visualized centerdist and sidedist connections–a Blender add-on was developed. The add-on offers two main functions, written in Python and compatible with Blender 4.0 and above. First: calculates each MESH object's parameter H(centerdist) to measure visual regularity (see Results, point 1, and Discussion, point 1). Second: generates an object that visualizes the centroid connections as segments underlying the H(centerdist) calculation (also referred to as 'Regularity'). Figure 7 shows a screenshot of the add-on.

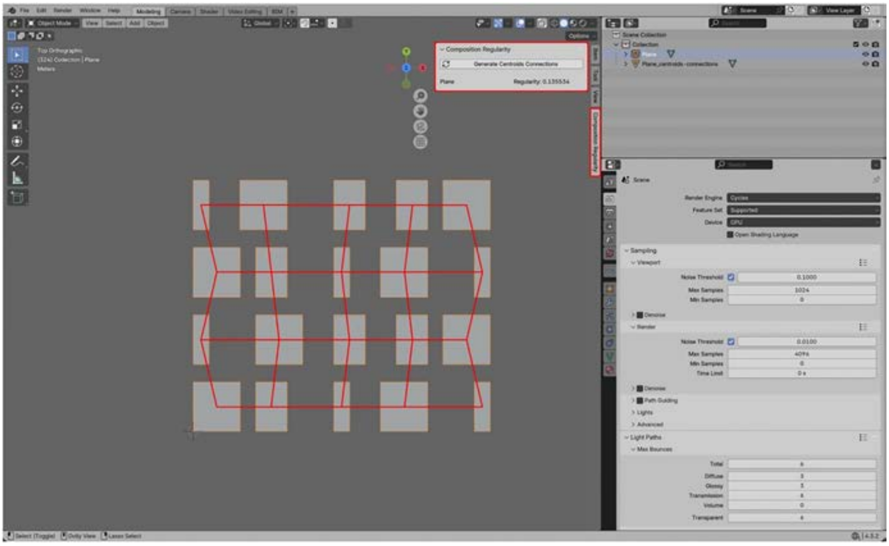

Fig. 7 Screenshot of the developed Blender add-on

Findings and Discussion

Regularity and Composition of Mathematical Attributes

The results indicate that five attributes– $H(y_{sidedist})$, $H(x_{centerdist})$, $H(y_{centerdist})$, $H(x_{centerdist})$ x $H(y_{centerdist})$, and H(centerdist)– form a group that best describes visual regularity. They exhibit near-perfect Pearson correlations (close to 1) with very low variability (<10%), meaning they increase uniformly with irregularity, approaching 0 for ideally regular compositions and theoretically reaching infinity for maximal irregularity. All these attributes derive from Shannon's metric entropy and share a mathematically defined range from 0 to infinity. They align with the concept of visual order: maximum order occurs when elements are evenly distributed, whereas absolute chaos—requiring infinitely unpredictable states—remains physically unattainable.

Despite its strong average results, $H(y_{sidedist})$ is a less reliable indicator compared to the other four ($H(x_{centerdist})$, $H(y_{centerdist})$, $H(x_{centerdist})$ x $H(y_{centerdist})$, and H(centerdist)). In an ideally regular composition (perfectly equal vertical and horizontal intervals), $H(y_{sidedist})$ reached 0 in 26 cases. In contrast, the other parameters reached zero only in additional test compositions with an even square matrix. Moreover, detailed analysis revealed that $H(x_{centerdist})$, $H(y_{centerdist})$, and H(centerdist) produced identical results for each composition, implying that $H(x_{centerdist})$ x $H(y_{centerdist})$ equals $H(centerdist)^2$. Therefore, H(centerdist) is the best reflection of visual regularity, with an average Pearson correlation of Mr = 0.9308 and a low variability (Vr = 9.75%). However, its range remains a comparative measure rather than an absolute one.

However, the limitations of the H(centerdist) index must be acknowledged. These constraints arise from the inherent limitations of Shannon entropy, which serves as the mathematical foundation for the parameter. Entropy calculations treat each piece

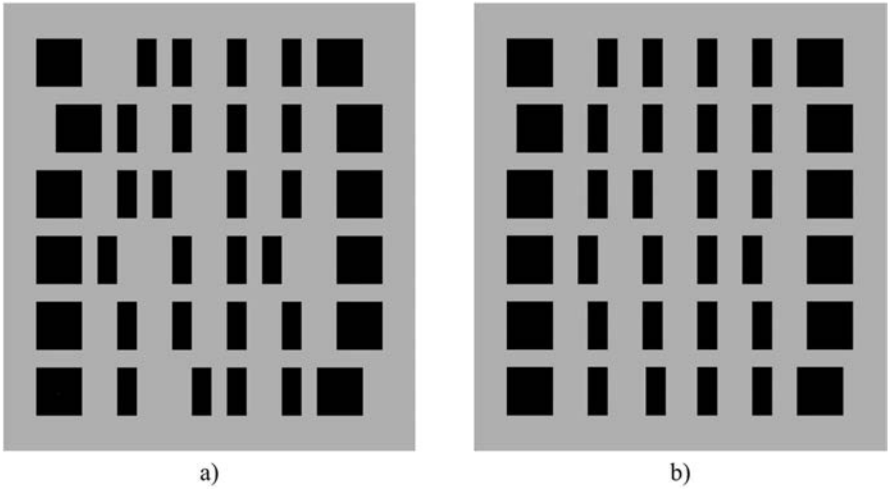

Fig. 8 Exemplary compositions (**a** and **b**) with the same H(centerdist) value

of information in a sequence as distinct, regardless of its actual degree of diversity. As mentioned, this translates into a lack of sensitivity to subtle regular changes, as shown in Fig. 8. Both compositions (a and b) share the same H(centerdist) value, although composition a) exhibits less regularity than b). In both cases, identical elements shift in the exact directions but by different amounts. While the distances between the centers of the composing elements remain the same, the differences in their values are more pronounced in the left composition.

Nevertheless, the other 25 attributes show a lower average correlation with the composition's regularity, and, importantly, they exhibit more significant variability. Therefore, they will describe the composition's visual regularity as statistically worse.

Regularity and Façade Pattern Type Correlation

Malewczyk et al. (2024) found a statistically significant, moderate (68.6%) correlation between composition type (as defined in their earlier work, 2022) and compositional regularity, suggesting that type alone does not determine regularity. This study applied a different approach using a larger dataset (245 vs. 12 compositions) derived from existing architectural objects. The average correlation between composition type (TYPE) and regularity (REG) was 71.45%, corroborating previous findings and confirming a strong association between visual regularity and composition type. While a 70% correlation does not prove that a given type inherently possesses regularity, these consistent results show that compositional regularity can be quantified using a mathematical coefficient.

Blender Add-on to Determine the Regularity of the Composition

The add-on to the Blender program, developed as part of the experiment described in this manuscript, represents its practical outcome. This tool offers two primary functionalities. First, it calculates the numerical value of the parameter H(centerdist), the metric entropy of the lengths of the centroid connections among the nearest compositional elements—regarded as the mathematical quantity that best captures a composition's visual regularity. Second, the program visualizes these centroid connections, reducing the subjectivity inherent in traditional regularity assessments and enabling standardized, repeatable results. Such objectivity plays a critical role in advancing research on architectural composition and its perception.

Another significant aspect involves the capacity to automatically process large volumes of compositional data. Such automation facilitates more robust testing of hypotheses regarding the relationship between composition and regularity. Consequently, integrating this tool with machine learning methods to analyze contemporary and historical architecture– or with generative algorithms that utilize regularity parameters as input– seems promising.

Despite high precision, the tool's performance depends on the quality of the input data. Currently, the script requires compositions to consist of non-touching rectangles on the XY plane, which limits applicability of the add-on. Future developments should analyze actual architectural elements beyond flat representations.

Conclusion

This study presents an innovative approach to analyzing the regularity of façade patterns, integrating digital tools, mathematical methods, and information theory. Drawing on Shannon entropy, the hypothesis formulated the existence of a mathematical coefficient that describes the regularity of architectural element compositions. The proposed parameter correlated with the perception of regularity at a level exceeding 90%, confirming the robustness of the adopted methodology and aligning with earlier findings based on human observation analysis (68.6% vs. 71.4%).

The developed script and a dedicated Blender add-on enable a precise, objective evaluation of façade designs, providing an essential bridge between subjective perception and statistical regularity analysis. This study enriches the theoretical understanding of the phenomenon by demonstrating a relationship between visual regularity and the distribution of distances between elements. It also introduces a practical tool intended for application in architectural design and design education.

Despite the strong results, the study suggests the need for further experiments to improve the coefficient's sensitivity to slight changes in regularity. The study proposes modifying the method of entropy calculation and incorporating alternative measures of variability. These results open new perspectives in the analysis of architectural complexity. They may contribute to a deeper discussion on the regularity of façade patterns in the context of different architectural styles and historical transformations.

In conclusion, the study forms an essential step towards integrating digital technologies with the theoretical analysis of architecture, providing both an innovative research tool and inspiration for further research on the perception of compositional regularity.

Funding Not applicable.

Availability of Data and Material On demand.

Code Availability Not applicable.

Declarations

Conflict of interest There are no conflict of interests.

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Sensitive data was not collected.

References

Amir, Ori, Irving Biederman and Kenneth J. Hayworth. 2011. The neural basis for shape preferences. *Vision Research* 51: 2198–2206. https://doi.org/10.1016/j.visres.2011.08.015

Arnheim, Rudolf. 1977. *The Dynamics of Architectural Form* (1st ed.). Oakland: The Regents of the University of California.

Belazi, Akram, Ahmed A. Abd El-Latif and Safya Belghith. 2016. A novel image encryption scheme based on substitution-permutation network and chaos. *Signal Processing* 128: 155-170. https://doi.org/10.1016/j.sigpro.2016.03.021

Benoit, Landry, et al. 2014. We simulate image acquisition in a machine vision system designed for seedling elongation to validate the image-processing algorithms used for root segmentation. *Computers and Electronics in Agriculture* 104: 84-92. https://doi.org/10.1016/j.compag.2014.04.001

Bertamini, Marco, et al. 2013. Implicit association of symmetry with positive valence, high arousal, and simplicity. *I-Perception* 4: 317-327.

Biederman, Irving. 1987. Recognition-by-components: A theory of human image understanding. *Psychological Review* 94(2): 115–147. https://doi.org/10.1037/0033-295X.94.2.115

Crompton, Andrew. 2012. The entropy of LEGO®. *Environment and Planning B: Planning and Design* 39 (1): 174–182.

Davis, Roland C. 1936. An evaluation and test of Birkhoff's aesthetic measure formula. *Journal of General Psychology* 15: 231–240.

Eysenck, Hans. 1941. The empirical determination of an aesthetic formula. *Psychological Review* 48: 83–92.

Friedenberg, Jay, et. al. 2021. Judged beauty of fractal symmetries. *Empirical Studies of the Arts* 40. https://doi.org/10.1177/0276237421994699

Grebenkina, Maria, et al. 2018. Edge-Orientation Entropy Predicts Preference for Diverse Types of Man-Made Images. *Frontiers in Neuroscience* 12: 678. https://doi.org/10.3389/fnins.2018.00678

Güzelci, Orkan Zeynel and Sema Alacam. 2019. A Study on Measuring Complexity in Muqarnas Patterns. *The Turkish Online Journal of Design Art and Communication* 9 (2), 191–201.

Güzelci, Orkan Zeynel, et al. 2021. Measuring the Entropy of Sinan's Muqarnas Patterns. *Nexus Network Journal* 23: 85-105. https://doi.org/10.1007/s00004-020-00521-0
Güzelci, Orkan Zeynel et al. 2020. Measuring the Entropy of Mass Housing Projects Through Spatial Relations. *XXIII Generative Art Conference - GA2020*, 229–237.
Katkov, Mikhali, Hila Harris and Dov Sagi. 2015. Visual perception of order-disorder transition. *Frontiers in Psychology* 6: 734. https://doi.org/10.3389/fpsyg.2015.00734
Kayaert, Greet, et al. 2005. Tuning for shape dimensions in macaque inferior temporal cortex. *European Journal of Neuroscience 22*. https://doi.org/10.1111/j.1460-9568.2005.04202.x
Koffka, Kurt. 1935. Principles of Gestalt Psychology. London: Lund Humphries
Krier, Rob. 1992. *Elements of architecture* (1st ed.). Academy Editions.
Kubilius, Jonas, Johan Wagemans and Hans Op de Beeck. 2014. Encoding of configural regularity in the human visual system. *Journal of Vision* 14(9): 11. https://doi.org/10.1167/14.9.11
Li, Yueping, Chunhua Wang and Hua Chen. 2017. A hyper-chaos-based image encryption algorithm using pixel-level permutation and bit-level permutation. *Optics and Lasers in Engineering* 90: 238–246. https://doi.org/10.1016/j.optlaseng.2016.10.020
Malewczyk, Michał, Antoni Taraszkiewicz and Piotr Czyż. 2022. Composition Patterns of Contemporary Polish Residential Building Facades. *Nexus Network Journal*. https://doi.org/10.1007/s00004-022-00614-y
Malewczyk, Michał, Antoni Taraszkiewicz and Piotr Czyż. 2024. Visual Perception of Regularity and the Composition Pattern Type of the Façade. *Buildings* 14: 1389. https://doi.org/10.3390/buildings14051389
Pecchinenda, Anaa., et. al. 2014. The pleasantness of visual symmetry: Always, never, or sometimes. *PLOS ONE* 9: 1-10. https://doi.org/10.1371/journal.pone.0092685
Pironio, Stefano. 2018. The certainty of randomness. *Nature* 556: 176–177.
Redies, Christoph, Anselm Brachmann and Johan Wagemans. 2017. High entropy of edge orientations characterizes visual artworks from diverse cultural backgrounds. *Vision Research* 133: 130-144
Shannon, Claude Elwood. 1948. A Mathematical Theory of Communication. *The Bell System Technical Journal* 27: 379–423, 623–656.
Stamps, Arthur E. 2004. Entropy and visual diversity in the environment. *Journal of Architectural and Planning Research* 21 (3): 239–256.
Stamps, Arthur E. 2012. Commentary on the entropy of LEGO. *Environment and Planning B: Planning and Design* 39 (1): 183–187.
Stamps, Arthur E. 2014. Creating stimuli with designed amounts of discrete Shannon information entropy. https://www.researchgate.net/publication/263967034. Accessed 27 April 2020.
Stanischewski, et al. 2020. Aesthetic Perception of Line Patterns: Effect of Edge-Orientation Entropy and Curvilinear Shape. *i-Perception* 11(5): 1–20. https://doi.org/10.1177/2041669520950749
Sun, Hua-Chun, Frederick A. A. Kingdom and Curtis L. Baker Jr. 2019. Perceived regularity of a texture is influenced by the regularity of a surrounding texture. *Scientific Reports* 9: 1637. https://doi.org/10.1038/s41598-018-37631-2
Wagemans, Johan, Felix A. Wichmann and Hans Op de Beeck. 2005. Visual perception I: Basic principles. In *Handbook of Cognition*, ed. Koen Lamberts and Rob Goldstone, 3-47. London: Sage.
Wu, Yue, et al. 2013. Local Shannon entropy measure with statistical tests for image randomness. *Information Sciences* 222: 323–342. https://doi.org/10.1016/j.ins.2012.07.049
Xu, Lu, et al. 2016. A novel bit-level image encryption algorithm based on chaotic maps. *Optics and Lasers in Engineering* 78: 17–25. https://doi.org/10.1016/j.optlaseng.2015.09.007

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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4.6 PUBLIKACJA VI

Weighted Shannon entropy as a quantitative measure of façade pattern regularity

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The article presents an original measure of facade pattern regularity, SVE (Shannon-Variance-Entropy), based on weighted Shannon entropy, which aims to quantitatively describe the internal diversity of a composition. The analysis showed that simply taking into account the distance between elements does not improve the accuracy of the regularity description. The variance of element proportions and angular relationships proved to be key factors, significantly increasing the indicator's consistency with aesthetic perception. The best results were obtained for the composite measure SVE_{DAS}, which combines all three components. This measure shows high consistency with expert assessments and effectiveness in the algorithmic generation of facade patterns. The use of the designated metric as a design parameter enables quantitative control of aesthetics, supporting sustainable design in line with SDG 11.

Keywords: urban planning; smart cities; urban development; city; data-driven design

Declarations: not applicable.

Funding: not applicable.

Conflicts of interest/Competing interests: there are no competing interests.

Availability of data and material: on demand.

Code availability: not applicable.

Ethics approval: not applicable.

Consent to participate: not applicable.

Consent for publication: sensitive data was not collected.

Weighted Shannon entropy as a quantitative measure of façade pattern regularity

Introduction

The aesthetics of urban space, especially the composition of architectural elements on building façades, play a key role in the perception of the quality of the urban environment (Malewczyk et al. 2022a, 2024; Samalavičius 2021). The regularity and geometric order of façades, especially the arrangement of windows, affect not only the visual experience of residents and users of public spaces, but also the sense of order, security and identity of a place (Ezz et al. 2024; Wang & Munakata, 2024). The pursuit of aesthetically pleasing, orderly and visually friendly urban spaces is directly in line with Sustainable Development Goal 11 (SDG 11), which calls for the creation of cities and neighborhoods that are safe, inclusive, sustainable and of high quality. Aesthetics and architectural legibility, including the geometric regularity of façades, support the perceived quality of urban life, a sense of local identity and comfort in the use of public space (Weber et al. 2008).

Despite growing interest in the problem of regularity in the context of the aesthetics of the built environment and its relationship to the broader psychophysical well-being of the users of that environment, there are still objective and unambiguous mathematical tools that would allow quantitative assessment of the geometric ordering of façade pattern. Malewczyk's publication from 2025 responded to this challenge by proposing the first version of an index describing the regularity of patterns, consisting of rectangles (symbolizing windows or façade panels) in a two-dimensional façade space. The author's index $H_{centerdist}$ corresponds to the entropy of the metric distance between the centers of adjacent compositional elements. Despite very high efficiency in the prediction of the degree of regularity by $H_{centerdist}$ (correlation of about 93%), in the author's opinion, there remains some field that needs improvement.

The main objective of this paper is to determine a modified façade pattern regularity measure index (SVE - Shannon-Variance-Entropy), based on the original $H_{(centerdist).}$ The new approach involves the introduction of metric entropy weighting, which should increase the sensitivity of the index to more subtle changes in composition regularity. An additional goal of the paper is to develop a generative algorithm and verify the feasibility of designing a composition by top-down determination of its regularity as a potential tool to support sustainable architectural design in line with SDG 11 goals.

The article is based on two research hypotheses. First, the weighted metric entropy index of the distance between the centers of adjacent compositional elements of a façade design describes the regularity of the design better than pure metric entropy. Second, the determined index of weighted metric entropy can be effectively used as an objective function in façade composition pattern generation algorithms.

This paper attempts to answer four research questions. First, how to mathematically define an optimal function that combines Shannon entropy with measures of spatial variance? Second, what façade composition parameters (sizes of compositional elements, spacing, location) most strongly influence the developed SVE index? Third, how does the SVE index correlate with the regularity of façade patterns, and is this correlation stronger than the original $H_{centerdist}$ index? Fourth, is it possible to algorithmically generate façade patterns through a top-down determination of the SVE parameter?

This article builds on the earlier study, however, based on an expanded research sample of 343 (original 245) compositions based on 49 residential, multi-family buildings nominated for the 2024 European Union Prize for Contemporary Architecture- Mies

Van der Rohe Award (EU Mies Award 2024) in the 'collective housing' category. A new statistical analysis methodology is also proposed.

The rest of the article presents an analysis of key concepts in the context of the current state of knowledge. The author focuses on measures of regularity in architecture, entropy in terms of information theory in terms of spatial analysis, and a review of ways to algorithmically generate compositions.

Measures of regularity in architecture

In the analysis of architectural forms, quantitative methods to objectively assess their regularity and order have become increasingly important. Research on regularity coefficients of façades focuses, among other things, on the analysis of distances between elements, rhythmicity and the occurrence of repetitive geometric patterns (Stiny & Mitchell 1978; Ilgaz et al. 2025; Med'dahi & Boussora 2021).

Applications of fractal geometry to façade analysis are also increasingly reported in the architectural literature, indicating a link between geometric complexity and the aesthetic and environmental perception of buildings (Bovill 1996; Salingaros 1998). Measures such as fractal dimension or complexity indices have been used to describe the structure of historic urban complexes and modern façades, demonstrating their potential as a tool for assessing the quality of space (Ali & Mustafa 2024; Lee 2014; Katona 2023).

Measures of symmetry and proportion, derived from classical theories of architectural composition (Wittkower 1949), are also an important category of analytical tools. Symmetry, both mirror and translational, plays an important role in the perception of regularity, as confirmed by psychological research and perceptual theory (Jacobsen 2006; Leder et al. 2004). These works indicate that structures with a high degree of regularity can be more easily recognized and positively evaluated by space users. A rich literature analysis of the issue of regularity measures in broader contexts was also made in Malewczyk's 2025 article.

Shannon's entropy and its applications

Entropy is a concept that was first introduced in the 19th century in thermodynamics to measure the chaotic nature of systems. In 1948, Claude Shannon also began, through entropy (according to Formula 1), to determine the average amount of information in a message, a concept that is particularly relevant in the context of information theory (Shannon 1948; Fourie 2012).

$$H = -\sum_{i=1}^{n} p_i \times log_2\, p_i$$

Formula 1 Entropy in information theory.

Since its introduction, Shannon's entropy has found widespread use in a variety of fields - including the description of the design process (Krus 2013), medical diagnosis (Benish 2020), and research on the relationship between diversity and aesthetic preferences (Redies et al. 2017; Stanischewski et al. 2020; Stamps 2004). The Shannon global entropy coefficient is also widely used in built environment analysis (Güzelci et al. 2020, 2021; Güzelci & Alacam 2019; Crompton 2012; Stamps 2012, 2014).

Based on metric entropy, which is independent of the length of information, the $H_{centerdist}$ index was developed (Malewczyk, 2025). It is a measure of the metric entropy of a sequence formed from the absolute distances between the centers of compositional elements (e.g., windows, façade panels) on a building façade. A study of 245 compositions based on 50 buildings nominated for the EU Mies Award 2024 in the 'collective housing' category found a 93% correlation between the $H_{centerdist}$ index and objective visual regularity. However, Malewczyk (2025) points out the limitations of the index, which does not consider the magnitude of disturbance, only the presence of disturbance, due to Shannon's entropy property, which is sensitive to variation but not to the magnitude of change. For example, the strings 1,3,7,3,5 and 2,35,192,79,192 have the same entropy, despite markedly different dispersion. Moreover, this indicator does not take into account the size of the compositional elements.

This problem can be solved by weighted entropy, proposed by Guiaşu (1971), which considers not only the probability of events, but also their importance (e.g., significance). An example of its application is in investment risk analysis (Nawrocki and Harding, 1986). Weighted entropy is being developed both theoretically (Ebanks 2010) and practically, including in computer science Kelbert et al. 2017) and urban scale built environment analysis (Boeing 2019; Huynh 2019; Wang 2018). However, no examples of its application in the analysis of architectural forms using metric entropy have yet been found.

$$H = -\sum_{i=1}^{n} w_i \times p_i \times log_2\, p_i$$

Formula 2 Entropy in information theory.

Algorithmic façade generation

Over the past two decades, algorithmic façade generation methods have become an important area of architectural research and experimentation, integrating parametric, optimization, environmental and artificial intelligence approaches. Of key importance is parametric design, which enables dynamic control over the geometry, structure and performance of a façade using tools such as Grasshopper, Ladybug or Octopus (Caetano 2020; Narangerel & Stouffs 2016; Shen 2018; Ramadan 2024). This makes it possible to simultaneously test and optimize forms for daylighting, shading, natural ventilation, and energy production (Narangerel & Stouffs 2016; Lahmar et al. 2022; Chen & Tang 2024).

In the context of the goals of SDG 11 and the topic of this article, research on the use of algorithmic methods to generate façades with aesthetic quality is particularly relevant. Rezakhani and Kim (2024) used genetic algorithms to optimize façades for aesthetics and visibility while maintaining appropriate sunlight parameters. Alagöz and Jamal (2024) used parametric design strategies in developing kinetic façades, striving for a balance between functionality and aesthetics. Similar issues are also addressed by Mahmoud and Elghazi (2016) and other authors (Engin et al. 2023; Wang, Sun, Shao & He 2024; Wang, Zhang, Zhang, Cui & He 2024; Cudzik 2019; Cudzik & Atasoy 2023; Cesbas et al. 2022).

More recently, there have also been attempts to apply artificial intelligence to the design process, including through the use of the Monte Carlo Tree Search (MCTS) algorithm in the early stages of design (Lin et al. 2025), as well as GAN algorithms to generate façades from images (Yu et al. 2020; Shan & Zhang 2022) and other inputs (Wan et al. 2023). Although these algorithms mainly focus on optimizing selected aspects, such as solarization, material consumption or energy efficiency with aesthetics, none of the publications found attempted to quantitatively encode façade aesthetics.

Materials and method

The present study is an expansion of Malewczyk's 2025 study. To increase the sensitivity of the study, the author partially uses, but also partially expands the original research sample. Modified statistical analysis procedures are also used to improve the quality of the results.

Materials

The study is based on materials, that is, 245 compositions of rectangles symbolizing windows or façade panels, on which the original Malewczyk (2025) study was based. The compositions were based on 50 photographs of multifamily buildings that were nominated in 2024 for the European Union Prize for Contemporary Architecture- Mies van der Rohe Award (EU Mies Award 2024) in the 'collective housing' category. In the original study, photographs were downloaded from the competition organizer's website (https://miesarch.com/archive). Basing the composition on examples of architecture nominated for such a prestigious award was to ensure the high quality of the research material.

Methods

Weighted entropy

The original Hcenterdist index in Malewczyk's 2025 study was determined based on metric entropy, which was calculated in a similar way to in the works of Stamps (2004, 2014), Cropmpton (2012), Güzelci (2019, 2021) or Stanischewski (2020). However, in order to increase the sensitivity of the determined index, the theoretical basis of Shannon's concept of weighted metric entropy, which was first written about by Guiaşu in 1971, is proposed. Of relevance to this article, from the perspective of the practical application of weighted entropy, are the works of Boeing (2019), Huynh (2019) and Wang and Zhao (2018). These works, although related to urban problems, make use of the author's important idea of weighted entropy with geometric relations.

Software

The study mainly used Blender version 4.3.2 for macOS. This program was used to create and process the study material and also to run scripts in Python version 3.12. The scripts used in the study used libraries such as bpy, bmesh, random, os, math, csv and io.

Creating compositions

In the original study, 49 two-dimensional compositions were created from photos of buildings nominated for the EU Mies Award 2024 in the 'collective housing' category. For one building, a composition was not created. In a further step, 4 variants were created based on each of the 49 original compositions, which clearly differed from each other and from the original composition in the degree of visual regularity. This was achieved by using such procedures as breaking symmetry, varying the distance between compositional elements, varying compositional elements among themselves and the like. In the end, 49 groups of compositions were formed, each of which had 5 compositions. A total of 245 compositions were created.

The current study uses 245 compositions from Malewczyk's 2025 study (source files available https://doi.org/10.34808/bemn-rd97) however, an additional 2 compositions were created within each of the 49 groups. The purpose of creating the additional compositions was to enrich the study sample with specimens that differed in visual regularity in a more subtle way, in order to be able to verify the sensitivity of the new weighted entropy-based indices. In the end, 343 compositions (245 original and 98 new) were collected for the study. The process of creating compositions using a group of 12 compositions as an example is visualized in Figure 1.

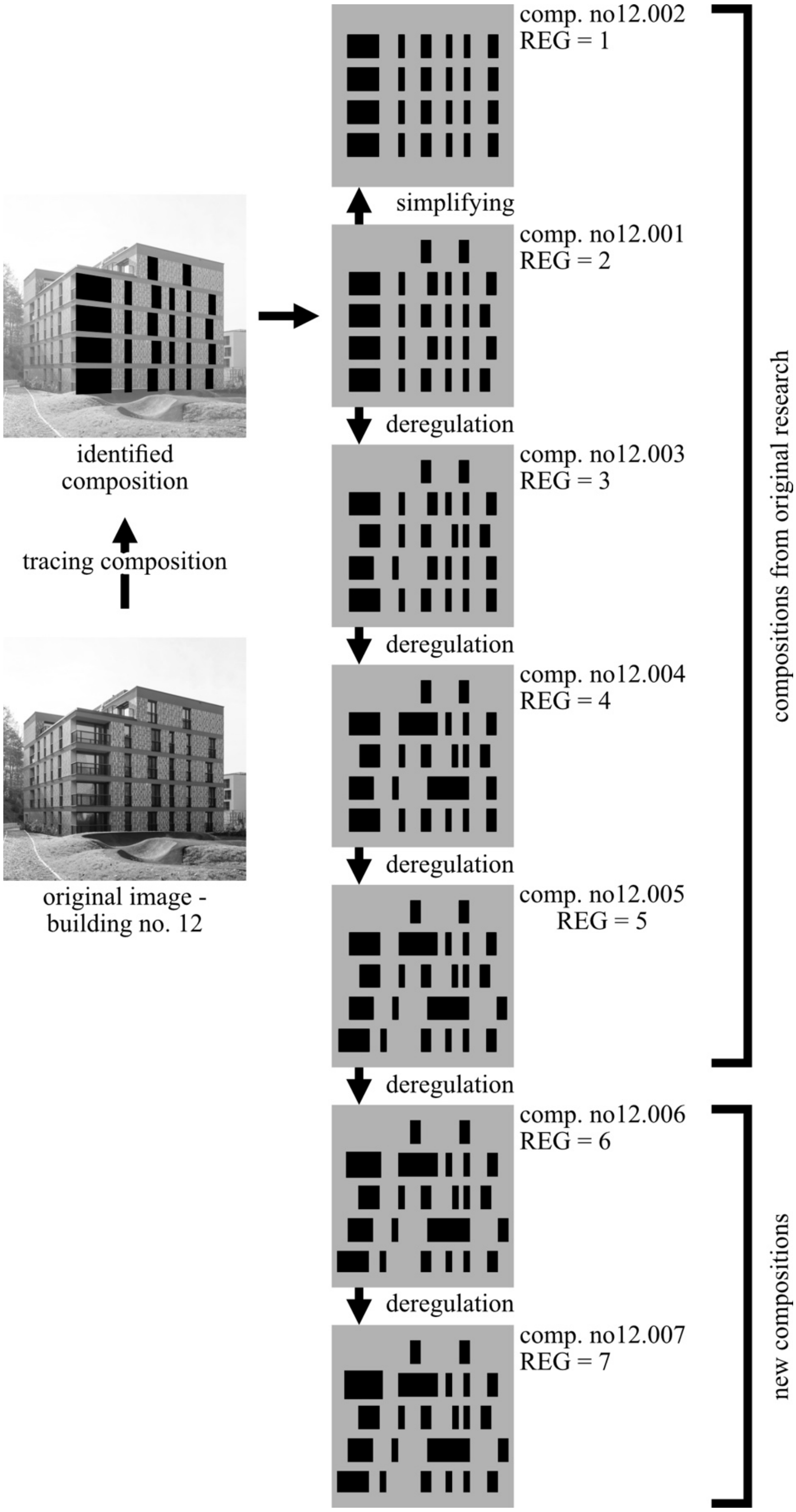

Fig. 1 The process of creating new compositions for the study based on the original material from Malewczyk's 2025 study using a group of 12 compositions as an example.

Composition analysis

In the original study, each composition was assigned a numerical value from 1 to 5, which determined the visual regularity of a given composition compared to the other specimens in the group (out of 49 groups). 1 meant the most regular while 5 meant the least regular. These values were coded as the 'REG' indicator. As the number of compositions in the 49 groups increased from 5 to 7 in the current study, the author assigned the new compositions the corresponding REG index values. In the current study, the REG index reaches values from 1 to 7. The higher the value, the more irregular the composition.

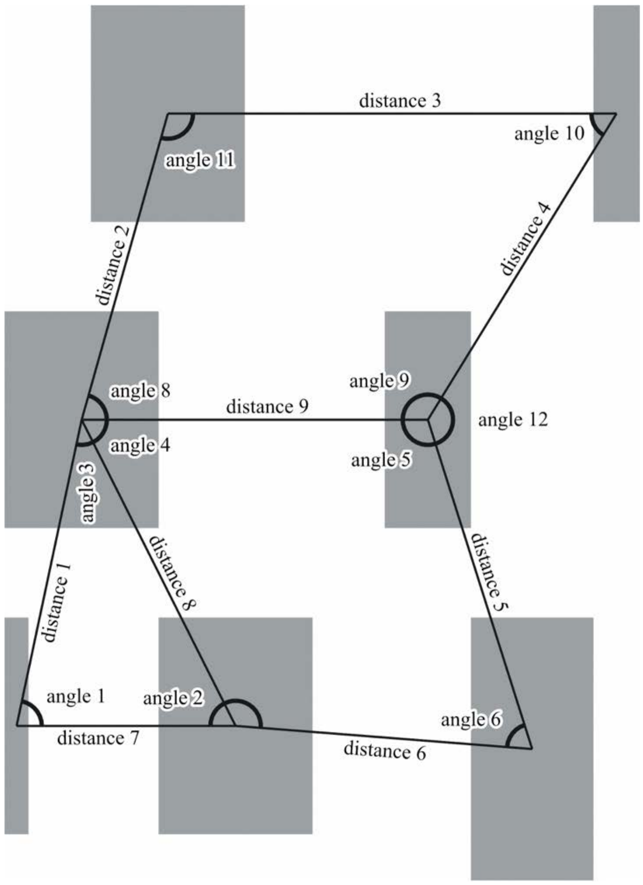

Fig. 2 Visualization of the connections determined in the study between the centers of the compositional elements and the angles between the connections.

The study used a script from the original Malewczyk (2015) study (source files available https://doi.org/10.34808/bemn-rd97) in Python, which was run in the internal Python interpreter in Blender. The script was adapted to the requirements of the current study. The task of the script was to perform mathematical analyses of the compositions. Based on the positions of the vertices of the rectangles forming the compositional patterns, the centers of each rectangle were determined and, further, the connections between the nearest neighboring rectangles. The interior angles formed between the connections of the centers of pairs of rectangles, which converge at a single point, were also determined. A visualization of the center connections and angles based on one of the compositions is shown in Figure 2.

In a further step, the script calculated the distances between the centers of the pairs of closest rectangles according to Formula 3.

$$d_{ij} = \sqrt{\left(cx_i - cx_j\right)^2 + \left(cy_i - cy_j\right)^2}$$

Formula 3. Distances between the centers of pairs of rectangles in the composition.

cx_i, cy_i- coordinates of the center of the i-th rectangle

cx_j, cy_j- coordinates of the center of the j-th rectangle

Further, the script determines the index $H_{centerdist}$according to Formula 4 - analogous to the way described in the article by Malewczyk (2025), the coefficient of variation ($CV_{distance}$) of distance d_{ij}, according to Formula 5, the combined coefficient of variation of shape CV_{shape}according to Formula 6 and the coefficient of variation of angles CV(angle)according to Formula 7.

$$H_{centerdist} = -\frac{\sum_{k=1}^{n} p_k \times log_2\, p_k}{N}$$

Formula 4 Entropy in information theory.

p - frequency of occurrence of the k-th unique value of $d_{(ij)}$.

N - number of elements (rectangles) in the composition

$$CV_{distance} = \frac{SD_{distance}}{M_{distance}}$$

Formula 5. coefficient of variation of the distance between the centers of pairs of rectangles in the composition.

$SD_{distance}$- standard deviation of the distance d_{ij}

$M_{distance}$- arithmetic mean of distance d_{ij}

$$CV_{shape} = \sqrt{\left(\frac{SD_{width}}{M_{width}}\right)^2 + \left(\frac{SD_{height}}{M_{height}}\right)^2}$$

Formula 6 Combined coefficient of variation of the shape of the rectangles in the composition.

SD_{width}, SD_{height}- standard deviation of width, height of rectangles

M_{width}, M_{height}- arithmetic mean of width, height of rectangles

$$CV_{angle} = \frac{SD_{angle}}{M_{angle}}$$

Formula 7. coefficient of variation of angles between the connections of the centers of pairs of nearest rectangles.

$SD_{(angl)\ (e)}$- standard deviation of the angles between the connections of centers

$M_{(angl)\ (e)}$- arithmetic mean of the angles between the connections of centers

In the final step, the script calculates seven proprietary metric weighted entropy indices (defined by Formula 8-14), based on the original $H_{centerdist}$ index (Malewczyk, 2025). These indices use the weighting of the variation in distance ($CD_{distance}$), from which the Hcenterdist index is calculated, the variation in the proportion of rectangles (CV_{shape}) in the compositional formula, and the variation in the angles (CV_{angle}) formed by lines connecting the centers of adjacent rectangles

$$SVE_D = H_{centerdist} \times CV_{distance}$$

Formula 8. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of these distances.

$$SVE_S = H_{centerdist} \times CV_{shape}$$

Formula 9. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of the dimensions of the rectangles.

$$SVE_A = H_{centerdist} \times CV_{angle}$$

Formula 10. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of the angles between the lines connecting the centers of adjacent rectangles.

$$SVE_{DS} = H_{centerdist} \times CV_{distance} \times CV_{shape}$$

Formula 11. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of these distances and the variation of the dimensions of the rectangles.

$$SVE_{DA} = H_{centerdist} \times CV_{distance} \times CV_{angle}$$

Formula 12. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of those distances and the variation of the angles between the lines connecting the centers of adjacent rectangles.

$$SVE_{SA} = H_{centerdist} \times CV_{shape} \times CV_{angle}$$

Formula 13. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of the dimensions of the rectangles and the variation of the angles between the lines connecting the centers of adjacent rectangles.

$$SVE_{DSA} = H_{centerdist} \times CV_{distance} \times CV_{shape} \times CV_{angle}$$

Formula 14. The metric entropy of the distances of the centers of adjacent rectangles, weighted by the variation of the distances, the variation of the dimensions of the *rectangles, and the variation of the angles between the lines connecting the centers of adjacent rectangles.*

Statistical analyses

In the original study, the Pearson correlation between the analyzed index and the REG value within each of the 49 groups was determined. Finally, the mean r-score, Pearson's correlation coefficient, was determined.

In the study described in this manuscript, it was decided to calculate the mean Spearman correlation coefficient, perform a rank concordance analysis and determine the sum of squares of rank differences. A change in the methodology of statistical analyses was decided because the REG coefficient is a categorical variable and not an interval variable, while the coefficients analyzed are interval variables and the differences between them may not be proportional to the differences between the ranks of the REG coefficient. Statistical analyses were performed through a Python script and run in Blender through the built-in Python interpreter.

Research Quality Control and Its Replication

To verify the script's correctness, functionality from the original version was retained - visualizing the connections of the centers of the nearest rectangles. Visualization of the angles formed by the lines connecting the centers of the nearest rectangles was also added. The experiment was conducted three times, obtaining the same results each time. The final version did not encounter any errors in the script's operation. All source files were made available in a public repository, allowing independent replication of the study.

Results

Analysis of five different formulas of the author's Shannon-Variance-Entropy (SVE) index showed significant differences in their ability to predict the regularity of building façade patterns. The five different weighting combinations were tested against the original $H_{centerdist}$ index (Malewczyk, 2025) in 49 composition groups, each of which contained seven patterns ranked according to the REG scale (from 1 to 7, with 1 indicating the greatest regularity and 7 indicating the greatest irregularity). Three complementary measures-Spearman's rank correlation coefficient, the percentage of correctly ordered pairs, and the sum of squares of rank differences-were used to assess the performance of the indicators. These measures were chosen to account for the ordinal nature of rank order regularity (REG) and to avoid the limitations of linear correlation assumptions (as in the case of the r-Pearson correlation coefficient).

Table 1 Summary of results of statistical analyses.

Measure	Spearman ρ	Correct Pairs (%)	Sum of Squared Rank Differences
$H_{centerdist}$	.929	88.7%	5.3
SVE_D	.871	90.0%	6.9
SVE_A	.919	92.1%	4.8
SVE_S	.946	93.2%	3.3
SVE_{DS}	.940	94.4%	3.1
SVE_{DA}	.949	95.3%	2.8
SVE_{AS}	.958	96.2%	2.5
SVE_{DAS}	.964	96.8%	2.0

A comparison of the performance of the SVE coefficient variants against the original $H_{centerdist}$ coefficient is shown in Table 1. The results show that SVE_{DAS} variance weighting for distance, proportion and angles) achieves the highest performance in all statistical indicators with a Spearman correlation of .964, a correct ordering of 96.8% and the lowest sum of squares of rank differences (2.0).

Correlation of individual variance components

The analysis revealed differential effects of individual variance components on the effectiveness of the SVE index. $SVE_{(D)}$ (ρ=.871) weighted by distance variance ($CV_{distance}$) shows the lowest effectiveness, even lower than the baseline $H_{centerdist}$ index (ρ=.929). An aspect that was completely ignored in the original study by Malewczyk (2025) is the variability of the angles formed between the connections of the centers of adjacent rectangles. The SVE_A weighted CV_{angle} obtained a Spearman correlation coefficient of ρ=.919 and is clearly superior to the baseline $H_{centerdist}$ in terms of the percentage of correctly ordered pairs (92.1% vs. 88.7%). However, the most significant component is the variation in the proportion of rectangles (CV_{shape}). SVE_S, weighted by CV_{shape} obtained a Spearman correlation coefficient of ρ=.946.

Verification of research hypotheses

The statistical analyses performed on the data collected in the conducted study made it possible to verify both research hypotheses and at the same time answer all four research questions.

Regarding hypothesis one, which assumed that weighted metric entropy better describes the regularity of the elevation pattern than unweighted entropy, it was confirmed for some of the variants of the SVE index. The combined SVE_{DAS} index performed 3.5 points better than the baseline $H_{centerdist}$ index and ordered 8.1 % points more pairs correctly. Thus, it was shown that all aspects-variability of distances, proportions and sizes of compositional elements and angles in the connection grid-are important in regularity analysis.

The high efficiency of the SVE_{DAS} index (ρ=.964), the very high percentage of correctly ordered pairs (96.8%) and its simplicity indicate the great potential of this measure as an objective function in generative algorithms. In the course of the research, such a generative tool was developed, whose mechanism of operation was based directly on the SVE_{DAS} indicator . The tool was developed as an add-on to Blender and made available under an open-source license. The tool definitions of six composition patterns created by Malewczyk, Taraszkiewicz and Czyż (2022b) as a composition typology of façades of residential, multi-family buildings. The tool allows you to select the specific type of composition you want to generate (according to the pattern definition), specify the regularity by providing expected numerical values for the interval of the SVE_{DAS} index and other parameters, such as the number of windows in rows and columns, window types, distances between window rows, heights of interstory strips and other basic physical aspects. Screenshots showing the user interface in various configurations are shown in Figure 3.

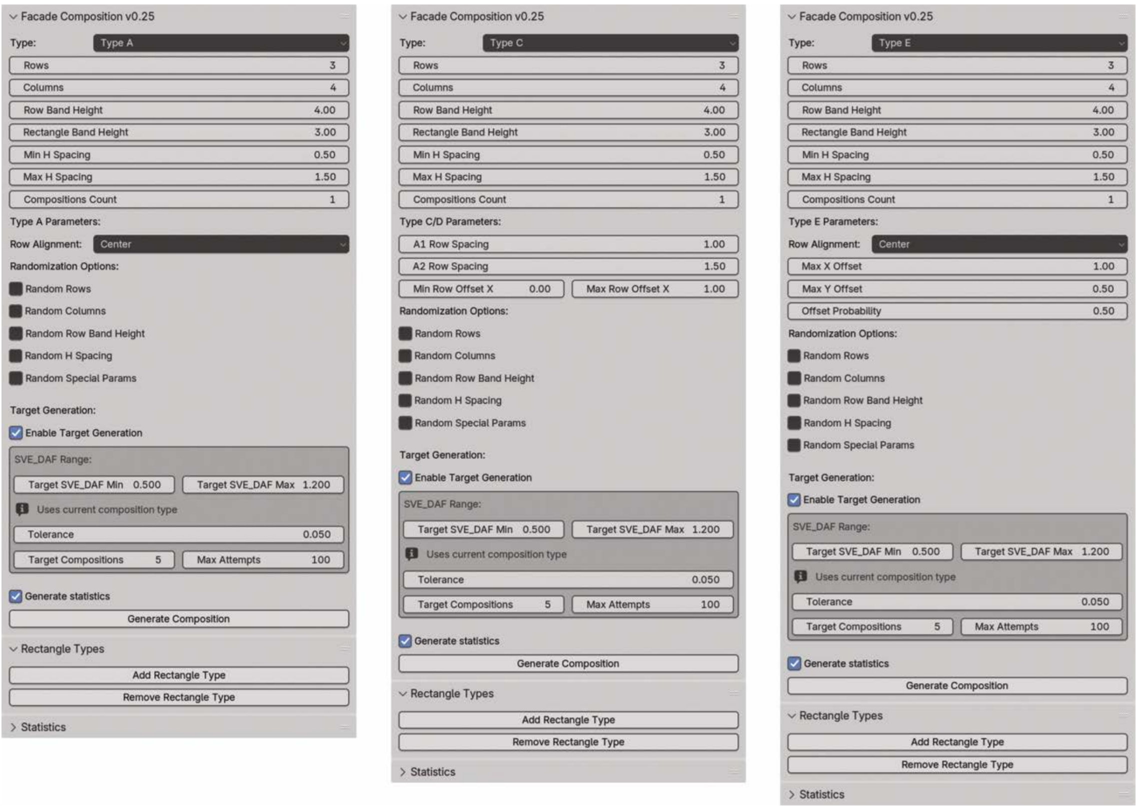

Fig. 3 User interface of the developed facade composition generator.

Thus, a tool has been obtained that allows the creation of an infinite number of elevation patterns with a given value of regularity, understood precisely as the value of the SVE index, which confirms its usefulness not only as a diagnostic measure, but also as an objective function in composition algorithms.

Discussion

The analysis of SVE (Shannon Variance-Entropy) variants reveals the complexity of the perception of regularity in facade patterns and the potential of advanced measures in their quantitative description. The results confirm that although simple entropy (Hcenterdist) is highly effective, its performance can be significantly improved by considering the internal variability of the pattern.

It has been shown that distance variance ($CV_{distance}$) as a standalone component not only fails to improve the accuracy of regularity description but may even worsen it. This suggests that information about the distances between elements (e.g., the centers of gravity of facade panels) does not constitute a sufficiently clear perceptual signal. This may be since local symmetry or rhythm often occur despite significant deviations from equal distances.

In turn, the variance of angles between lines connecting the centers of compositional elements, although moderately effective as a standalone component, has a strong effect when combined with other features. This points to the importance of directional relationships in pattern perception, especially in more complex and irregular arrangements. Angular differences can act as ‘visual disturbances’ of rhythm and controlling them affects the perception of order.

The strongest component was found to be the variance in the proportions of elements (CV_{shape}). Its high effectiveness, both on its own and in combination, confirms the intuitive understanding of regularity as the repetition of forms with similar dimensions, which is consistent with previous qualitative studies on rhythm, proportion, and scale in architectural compositions.

The best results were obtained for multi-component variants, especially SVE_{DAS}, which combines all three components: distance, angle, and proportion. Each of them describes a different aspect of perception: spatial arrangement, directional relationships, and similarity of forms, which ensures high analytical resolution and the ability to capture subtle differences in the order of the composition.

The method of evaluating the effectiveness of the measures is also worth noting. The use of three indicators (Spearman's rank correlation, pair order accuracy, and sum of rank differences) allowed for a multifaceted evaluation that better reflects the nature of ordinal data and avoids overinterpretation of linear correlation.

As a result, SVEDAS can serve as an analytical tool and indicator supporting the design process. Its high consistency with expert assessments confirms its operational potential-both in the analysis of existing designs and in the automatic generation of new variants, which has been tested during the research. The algorithm, which uses the SVE_{DAS} value as a control parameter, confirmed the functionality of the formula and its usefulness in design applications. Examples of compositions generated by the algorithm are shown in Figure 4.

The ability to define regularity through numerical values or to optimize the facade design in relation to a minimum regularity index (understood as the SVE_{DAS} value) opens a new chapter in architectural aesthetics, in line with the idea of data-driven design. The key point here is that SVE_{DAS} does not describe indirect factors influencing aesthetics (such as sunlight), but aesthetics itself. By taking this index into account, designers gain the ability to objectively compare aesthetic aspects, which can contribute to the creation of architecture that is more inclusive, sustainable, and supportive of SDG 11.

Conclusion

In conclusion, in the course of the conducted study based on the materials and method of the 2025 Malewczyk study, statistical analyses showed that the SVE_{DAS} index , that is, the metric entropy of the lengths of the connections between the centers of the compositional elements weighted by the indicators of the variation of these lengths, the angles in the grid of the connections of the centers of the compositional elements and the variation of the proportions of the compositional elements, proved to be extremely effective in predicting the visual regularity of the compositional designs. A correlation of the author's index with expert assessments of compositional regularity of more than 96% was obtained.

For nearly 97% of the pairs correctly ordered the regularity of the composition. The original $H_{centerdist}$ index (Malewczyk 2025) admittedly also achieved high results (93% correlation and 89% correctly ordered pairs), but most importantly, the new SVE_{DAS} index shows much greater sensitivity to subtle differences in regularity.

In the course of the work, an add-on for Blender was also developed to generate façade composition patterns, based on the typology of composition patterns by Malevich, Taraszkiewicz and Czyż (2022b). The add-on has the ability to generate compositions with a predefined range of SVE_{DAS} factor . Thus, the possibility of using the determined compositional regularity coefficient as an input function in façade generative algorithms was verified. Optimizing façade design for regularity promotes the goals of SDG 11 through architectural design. The optimization of regularity serves to improve architectural aesthetics and further- supports the creation of safe, inclusive, sustainable and high-quality cities and neighborhoods.

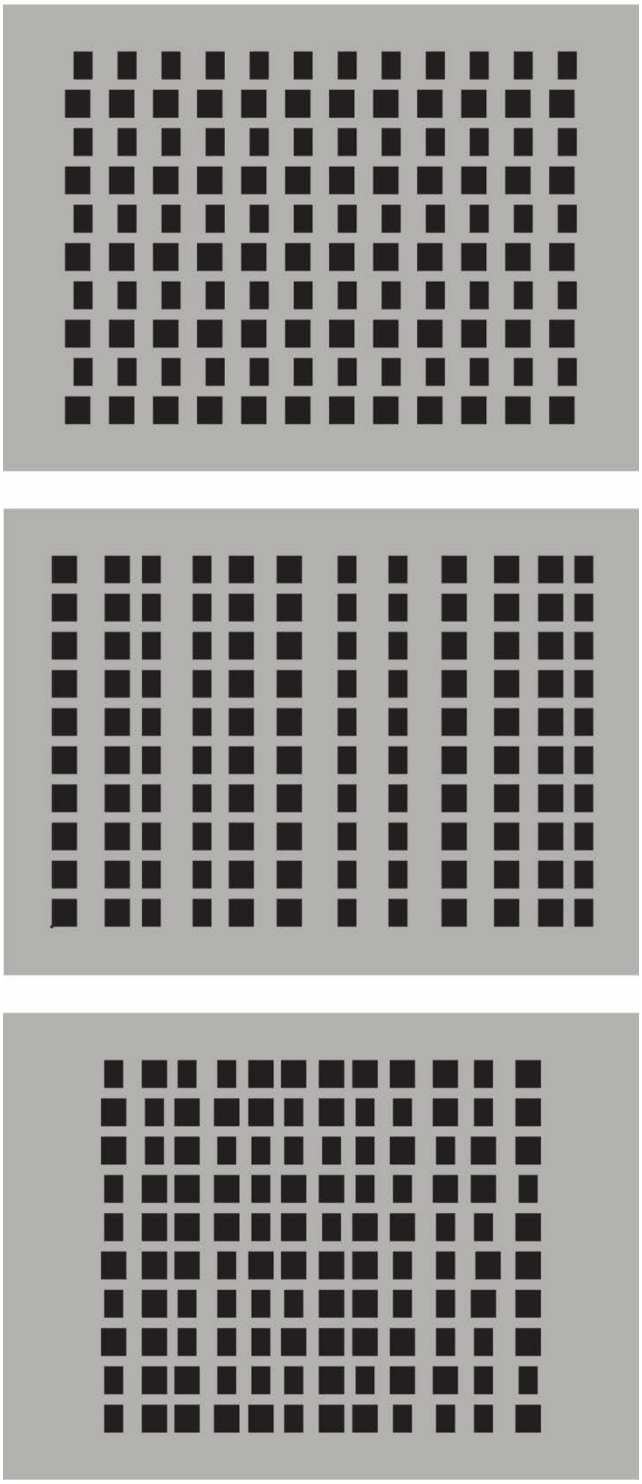

Fig. 4 Three examples of facade compositions with a comparable degree of regularity, generated by the developed algorithm..

References

Ali, Lana Abubakr, and Faris Ali Mustafa. 2024. Fractal dimensional analysis of building façades: The case of office buildings in Erbil City. *Fractal and Fractional* 8(12): 746. https://doi.org/10.3390/fractalfract8120746

Alagöz Konur, Meryem, and Marwa Jamal. 2024. design approaches of parametric kinetic wall systems: Innovative architectural solutions. *Konya Sanat (Konart)* 7: 26-43. https://doi.org/10.51118/konsan.2024.41

Benish, William A. 2020. a review of the application of information theory to clinical diagnostic testing. *Entropy* 22(1): 97. https://doi.org/10.3390/e22010097

Besbas, Soumaya, Francesco Nocera, Noureddine Zemmouri, Mohamed Amine Khadraoui, and Asma Besbas. 2022. Parametric-Based Multi-Objective Optimization Workflow: Daylight and Energy Performance Study of Hospital Building in Algeria. *Sustainability* 14(19): 12652. https://doi.org/10.3390/su141912652

Boeing, Geoff. 2019. urban spatial order: street network orientation, configuration, and entropy. *Applied Network Science* 4: 67. https://doi.org/10.1007/s41109-019-0189-1

Bovill, Carl. 1996. fractal geometry in architecture and design. Boston: Birkhäuser.

Caetano, Inês, António Leitão, and Fernando Bastos. 2020. from architectural requirements to physical creations: An algorithmic-based approach for façade design. *Journal of Façade Design and Engineering* 8(2): 59-80. https://doi.org/10.7480/jfde.2020.2.4543

Cameron, Deborah. 1985. feminism and linguistic theory. New York: St. Martin's Press.

Cameron, Deborah. 1997. theoretical debates in feminist linguistics: questions of sex and gender. In Gender and discourse, ed. Ruth Wodak, 99-119. London: Sage Publications.

Chen, Ping, and Hao Tang. 2024. A framework for adaptive façade optimization design based on building envelope performance characteristics. *Buildings* 14(9): 2646. https://doi.org/10.3390/buildings14092646

Crompton, Andrew. 2012. the entropy of LEGO®. *Environment and Planning B: Planning and Design* 39 (1): 174-182.

Cudzik, Jan. 2019. changes taking place in the kinetic architecture over the 20th and 21st centuries. *Space and Form* 38: 21-32. https://doi.org/10.21005/pif.2019.38.b-02

Cudzik, Jan, and Arif Atasoy. 2023. the impact of contemporary technology on shell structures: material and light solutions. *Journal of the International Association for Shell and Spatial Structures* 61: 34-45. https://doi.org/10.20898/j.iass.2022.022

Ebanks, Bruce. 2010. weighted entropies. *Open Mathematics* 8(3): 602-615. https://doi.org/10.2478/s11533-010-0026-3

Engin, Abdul Samet, and Ahmet Emre Dincer. 2023. morphological composition assessment of kinetic façade designs via AHP and TOPSIS methods based on façade components and design inputs. *International Journal of Architectural Computing* 22(3): 323-352. https://doi.org/10.1177/14780771231209457

Ezz, Mohamed Salah, Essam Odah, Saleh Baharetha, Abd Al-Kader A. Al Sayed, and Doaa A. H. Salem. 2024. Analytical examination of dynamic elements in modern architectural façades for advanced structural aesthetics. *Frontiers in Built Environment* 10. https://doi.org/10.3389/fbuil.2024.1302380

Fourie, Ingrid. 2012. entropy and information theory. 2nd ed. *Online Information Review* 36(3): 481-482. https://doi.org/10.1108/14684521211241477

Güzelci, Orkan Zeynel and Sema Alacam. 2019. a Study on Measuring Complexity in Muqarnas Patterns. *The Turkish Online Journal of Design Art and Communication* 9 (2), 191-201.

Güzelci, Orkan Zeynel et al. 2020. Measuring the Entropy of Mass Housing Projects Through Spatial Relations. XXIII Generative Art Conference - GA2020, 229-237.

Güzelci, Orkan Zeynel, et al. 2021 Measuring the Entropy of Sinan's Muqarnas Patterns. *Nexus Network Journal* 23: 85-105. https://doi.org/10.1007/s00004-020-00521-0

Guiaşu, Silviu. 1971. weighted entropy. *Reports on Mathematical Physics* 2(3): 165-179. https://doi.org/10.1016/0034-4877(71)90002-4

Huynh, Hoai Nguyen. 2019. spatial point pattern and urban morphology: Perspectives from entropy, complexity, and networks. *Physical Review E* 100(2): 022320. https://doi.org/10.1103/PhysRevE.100.022320

Ilgaz, Elif Ece, Michael S. Bittermann, and Dilek Yıldız Özkan. 2025. on the regularity of opening patterns in building façades. *Nexus Network Journal* 27(2): 373-389. https://doi.org/10.1007/s00004-025-00815-1

Jacobsen, Thomas. 2006. bridging the arts and sciences: A framework for the psychology of aesthetics. *Leonardo* 39(2): 155-162. https://doi.org/10.1162/leon.2006.39.2.155

Katona, Vilmos. 2023. The hidden dimension of façades: Fractal analysis reveals composition rules in classical and Renaissance architecture. *Fractal and Fractional* 7(3): 257. https://doi.org/10.3390/fractalfract7030257

Kelbert, Mark, Izabella Stuhl, and Iouri M. Suhov. 2017 Weighted Entropy: Basic Inequalities. *Modern Stochastics: Theory and Applications* 4(3): 233-252. https://doi.org/10.15559/17-VMSTA85

Krus, Paul. 2013. information entropy in the design process. In ICoRD'13, edited by Amit Chakrabarti and Rajeev Prakash. Lecture Notes in Mechanical Engineering. Springer, India. https://doi.org/10.1007/978-81-322-1050-4_8

Lahmar, Imene, Alessandro Cannavale, Francesco Martellotta, and Noureddine Zemmouri. 2022. The impact of building orientation and window-to-wall ratio on the performance of electrochromic glazing in hot arid climates: A parametric assessment. *Buildings* 12(6): 724. https://doi.org/10.3390/buildings12060724

Leder, Helmut, Benno Belke, Andries Oeberst, and Dorothee Augustin. 2004. a model of aesthetic appreciation and aesthetic judgments. *British Journal of Psychology* 95(4): 489-508. https://doi.org/10.1348/0007126042369811

Lee, Minsuk Sang. 2014. application of fractal geometry to architectural design. Architectural Institute of Korea.

Lin, Victor Yu-Chieh, and Shen-Guan Shih. 2025. AI-augmented parametric façade design: Exploring MCTS for early-stage decision-making. *Nexus Network Journal.* https://doi.org/10.1007/s00004-025-00822-2

Mahmoud, Ayman Hassaan Ahmed, and Yomna Elghazi. 2016. Parametric-based designs for kinetic façades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal façade patterns. *Solar Energy* 126: 111-127. https://doi.org/10.1016/j.solener.2015.12.039

Malewczyk, Michal. 2025. the mathematical regularity coefficient for façade patterns. *Nexus Network Journal*. https://doi.org/10.1007/s00004-025-00827-x

Malewczyk, Michal, Antoni Taraszkiewicz, and Piotr Czyż. 2022a. Preferences of the façade composition in the context of its regularity and irregularity. *Buildings* 12: 169. https://doi.org/10.3390/buildings12020169

Malewczyk, Michal, Antoni Taraszkiewicz, and Piotr Czyż. 2022b. Composition Patterns of Contemporary Polish Residential Building Façades. *Nexus Network Journal*. https://doi.org/10.1007/s00004-022-00614-y

Malewczyk, Michal, Antoni Taraszkiewicz, and Piotr Czyż. 2024. visual perception of regularity and the composition pattern type of the façade. *Buildings* 14: 1389. https://doi.org/10.3390/buildings14051389

Med'dahi, Karim, and Hassan Boussora. 2021. Parametric description of façade order using Eysenck's method. *Nexus Network Journal* 23(3): 667-688. https://doi.org/10.1007/s00004-021-00546-z

Narangerel, Amartuvshin, Ji-Hyun Lee, and Rudi Stouffs. 2016. daylighting-based parametric design exploration of 3D façade patterns. In Complexity & Simplicity - Proceedings of the 34th eCAADe Conference, vol. 2, ed. Aulikki Herneoja, Toni Österlund, and Piia Markkanen, 379-388. Oulu: University of Oulu. https://doi.org/10.52842/conf.ecaade.2016.2.379

Nawrocki, David N., and William H. Harding. 1986. state-value weighted entropy as a measure of investment risk. *Applied Economics* 18: 411-419. https://doi.org/10.1080/00036848600000038

Ramadan, Lina A., Ashraf A. Elmokadem, and Nancy Badawy. 2024. Multi-objective optimization framework based on review of form-finding of architectural parametric forms. *International Journal of Architectural Computing*. https://doi.org/10.1177/14780771241299595

Redies, Christoph, Anselm Brachmann and Johan Wagemans. 2017. high entropy of edge orientations characterizes visual artworks from diverse cultural backgrounds. *Vision Research* 133: 130-144

Rezakhani, Mojgan, and Sung-Ah Kim. 2024. Genetic algorithm-driven optimization of pattern for parametric façade design based on support position data to increase visual quality. *Buildings* 14(4): 1086. https://doi.org/10.3390/buildings14041086

Salingaros, Nikos A. 1998. A scientific basis for creating architectural forms. *Journal of Architectural and Planning Research* 15(4): 283-293.

Samalavičius, Almantas L. 2021. Revisiting façades: A note on symmetry as an aesthetic principle. *Symmetry: Culture and Science*. https://doi.org/10.26830/symmetry_2021_3_405

Shan, Liang, and Lixin Zhang. 2022. Application of intelligent technology in façade style recognition of Harbin modern architecture. *Sustainability* 14: 7073. https://doi.org/10.3390/su14127073

Shannon, Claude E. 1948. a mathematical theory of communication. *Bell System Technical Journal* 27(3): 379-423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Shen, Xiaofei. 2018. "Environmental Parametric Multi-Objective Optimization for High Performance Façade Design." In Learning, Adapting and Prototyping - Proceedings of the 23rd CAADRIA Conference, Vol. 2, edited by T. Fukuda, W. Huang, P. Janssen, K. Crolla, and S. Alhadidi, 103-112. Beijing, China: Tsinghua University, May 17-19, 2018. https://doi.org/10.52842/conf.caadria.2018.2.103.

Stanischewski, et al. 2020. Aesthetic Perception of Line Patterns: Effect of Edge-Orientation Entropy and Curvilinear Shape. *i-Perception* 11(5): 1-20. https://doi.org/10.1177/2041669520950749

Stiny, George, and William J. Mitchell. 1978. the Palladian grammar. *Environment and Planning B: Planning and Design* 5(1): 5-18.

Stamps, Arthur E. 2004. Entropy and visual diversity in the environment. *Journal of Architectural and Planning Research* 21 (3): 239-256.

Stamps, Arthur E. 2012. commentary on the entropy of LEGO. *Environment and Planning B: Planning and Design* 39 (1): 183-187.

Stamps, Arthur E. 2014. Creating stimuli with designed amounts of discrete Shannon information entropy. https://www.researchgate.net/publication/263967034. Accessed April 27, 2020.

Wang, Bo, Liang Sun, Zebiao Shao, and Ying He. 2024. Multi-objective optimization of a novel dynamic concentrated skin system considering daylight, building skin capacity, and visual space. *Building and Environment* 256: 111472. https://doi.org/10.1016/j.buildenv.2024.111472

Wang, Bo, Xinshuo Zhang, Mengli Zhang, Yong Cui, and Ying He. 2024. Development of novel variable building skin with solar concentrating technology for obtaining energy benefits and optimizing indoor daylighting. *Energy and Buildings* 310: 114081. https://doi.org/10.1016/j.enbuild.2024.114081.

Wang, Chaojun, and Hongrui Zhao. 2018. Spatial Heterogeneity Analysis: Introducing a New Form of Spatial Entropy. *Entropy* 20(6): 398. https://doi.org/10.3390/e20060398

Wang, Fei, and Jun Munakata. 2024. Assessing effects of façade characteristics and visual elements on perceived oppressiveness in high-rise window views via virtual reality. *Building and Environment* 266: 112043. https://doi.org/10.1016/j.buildenv.2024.112043

Wan, Da, Runqi Zhao, Sheng Zhang, Hui Liu, Lian Guo, Pengbo Li, and Lei Ding. 2023. A deep learning-based approach to generating comprehensive building façades for low-rise housing. *Sustainability* 15(3): 1816. https://doi.org/10.3390/su15031816

Weber, Robert, Jens Schnier, and Thomas Jacobsen. 2008. aesthetics of streetscapes: Influence of fundamental properties on aesthetic judgments of urban space. *Perceptual and Motor Skills* 106(1): 128-146. https://doi.org/10.2466/pms.106.1.128-146

Wittkower, Rudolf. 1949. architectural Principles in the Age of Humanism. London: Alec Tiranti.

Yu, Qiang, Jihad Malaeb, and Wei Ma. 2020. architectural façade recognition and generation through generative adversarial networks. In Proceedings of the 2020 International Conference on Big Data & Artificial Intelligence & Software Engineering (ICBASE), 310-316. Bangkok, Thailand. https://doi.org/10.1109/ICBASE51474.2020.00072

5. PODSUMOWANIE

Niniejsza rozprawa opisuje badania przeprowadzone w ramach projektu badawczego, poświęconego analizie kompozycji elementów architektonicznych na fasadach budynków mieszkalnych, wielorodzinnych w kontekście ich percepcji wizualnej. Szczególnie istotnym aspektem dla opisywanego w niniejszej rozprawie projektu badawczego jest zagadnienie regularności wizualnej, która – w świetle przeprowadzonych badań – koreluje z preferencjami estetycznymi. Rozprawa opiera się na zbiorze sześciu publikacji, odpowiadających kolejnym etapom projektu. Publikacja I została poświęcona diagnozie – identyfikacji problemu, jakim jest kwestia nieregularności wizualnej definiującej (według autorów Publikacji) współczesną architekturę mieszkaniową. Publikację II poświęcono na identyfikację wzorców projektowych w rozumieniu Christophera Alexandra (1977) w odniesieniu do kompozycji elementów architektonicznych na elewacjach budynków wielorodzinnych. Na łamach artykułu opisano autorską typologię wzorów kompozycyjnych, która porządkuje kompozycje fasad budynków mieszkalnych, wielorodzinnych w analizowanej próbie. Sześć wzorów, składających się na typologię, zdefiniowano dzięki szczegółowej analizie sposobu kształtowania kompozycji, szczególnie pod kątem budowania regularności wizualnej. Trzeci etap, czyli Publikacje III, IV oraz V, to ewaluacja opisanej w Publikacji II typologii wzorów kompozycyjnych oraz badania nad percepcją kompozycji w kontekście tejże typologii oraz regularności wizualnej. W Publikacjach III oraz IV opisano badania ankietowe z udziałem ludzi, natomiast w Publikacji V – eksperyment obliczeniowy przeprowadzony w środowisku in silico. Ostatni, czwarty etap, to etap aplikacyjny. Na łamach Publikacji V oraz Publikacji VI opisano dwa narzędzia cyfrowe, udostępnione na licencji open-source – narzędzie do analizy współczynnika regularności wizualnej kompozycji elementów na fasadzie oraz generator kompozycji o zadanym stopniu regularności i zgodnie z typologią opisywaną w Publikacji II.

Analiza współczesnych, polskich, wybitnych przykładów architektury mieszkaniowej, zawarta w Publikacji I, wskazuje na wyraźną tendencję w kreowaniu estetyki opartej o nieregularność wizualną. Nieregularność tę, w obrębie analizowanych przykładów, osiągano na trzy różne sposoby – poprzez nieregularność formy, kompozycji fasad oraz zastosowanego materiału. W opisie problematyki badawczej, zawartym w niniejszej rozprawie, nakreślono możliwe przyczyny, z jakich wynika takowa tendencja. Nasuwają się jednak pytania – czy tendencja ta jest właściwa? W jaki sposób architekci powinni projektować, aby odpowiednio odpowiadać na oczekiwania i potrzeby użytkowników architektury? W niniejszej rozprawie skupiono się na aspekcie nieregularności związanej z kompozycją fasad w szczególności w obszarze budownictwa mieszkaniowego, wielorodzinnego. Aby jednak udzielić odpowiedzi na powyżej postawione pytania, niezbędne jest dogłębne zrozumienie sposobu, w jaki powstają kompozycje fasad budynków. Niezbędna jest także ich ewaluacja oraz poznanie preferencji ludzi względem sposobu kształtowania układów elewacyjnych.

Należy w tym miejscu odnieść się do postawionej w niniejszej rozprawie hipotezy badawczej o istnieniu skończonej liczby wzorów kształtowania kompozycji, składających się z elementów architektonicznych takich jak okna, balkony czy panele elewacyjne, na fasadach budynków mieszkalnych, wielorodzinnych. Hipoteza ta znalazła silne potwierdzenie w analizowanym materiale empirycznym. Wyabstrahowano sześć wzorów kompozycji, którymi – w obrębie badanej próby współczesnych polskich budynków wielorodzinnych – można opisać wszystkie zidentyfikowane układy fasad budynków zamieszkania zbiorowego. Wzory te zdefiniowano i opisano w Publikacji II literami od A do F. Należy jednak podkreślić, że są to ogólne zasady, według których można układać elementy kompozycyjne względem siebie. Te sześć wzorów to sześć zasad, które można stosować w izolacji w obrębie jednej fasady, jak i łączyć w różnych konfiguracjach. Zasady te są formułowane w sposób sprzyjający ich algorytmicznemu zapisowi. Potencjał przeniesienia tej typologii na inne konteksty funkcjonalne, kulturowe i formalne wymaga jednak dalszej weryfikacji badawczej.

Zidentyfikowanie wzorców kształtowania układów elewacji i wstępne potwierdzenie hipotezy badawczej pozwoliło na realizację kolejnego etapu projektu badawczego – ewaluację opracowanej typologii. Zarówno wyniki badań ankietowych z udziałem ochotników, jak i wyniki badań in silico (Publikacje III oraz V) potwierdziły istnienie wyraźnej korelacji pomiędzy typem wzoru kompozycyjnego a stopniem regularności wizualnej. Na podstawie wyników tych badań związek ten można szacować na poziomie około 70%. Jest to korelacja, którą – według literatury naukowej – należy uznawać za silną (Cohen 1988, Evans 1996). Jednocześnie oznacza to, że istotna część wariancji (około 30%) pozostaje związana z innymi czynnikami: m.in. szczegółową konfiguracją elementów, ich zróżnicowaniem, kontekstem prezentacji bodźców czy indywidualnymi różnicami w percepcji. Znając tę zależność, możemy w przybliżeniu prognozować, jak zastosowanie konkretnego typu wzoru kompozycyjnego wpłynie na postrzegany stopień regularności fasady w populacjach zbliżonych do badanych prób. Prognoza ta ma charakter probabilistyczny i nie eliminuje roli innych uwarunkowań estetycznych i kontekstowych.

Istotnym efektem praktycznym opisywanego w niniejszej rozprawie projektu badawczego są opisane w Publikacji V oraz VI wskaźniki $H_{centerdist}$ oraz SVE_{DAS}, których korelację ze stopniem regularności wizualnej kompozycji ustalono – w odniesieniu do analizowanego zbioru 245/343 kompozycji prostokątów – na poziomie odpowiednio ok. 93 oraz 96%. Wskazuje to na bardzo silną zależność pomiędzy wyznaczonymi parametrami a stopniem regularności wizualnej w obrębie zastosowanej operacjonalizacji i badanych danych, choć nie przesądza o ich uniwersalności w każdym możliwym kontekście projektowym. Ponadto, wskaźniki te określają, która z dwóch kompozycji jest bardziej lub mniej regularna z dokładnością na poziomie odpowiednio ok. 88 oraz 96% w ramach analizowanych par bodźców.

W ramach badań opracowano także dwa narzędzia typu open-source. Pierwsze z nich, opisywane w ramach Publikacji V, oblicza wskaźnik Hcenterdist dla zadanej kompozycji. Narzędzie to ma znaczący potencjał zastosowania w dalszych badaniach nad estetyką architektury i jej percepcją – zarówno w odniesieniu do architektury współczesnej, jak i historycznej. Aby jednak narzędzie było dokładniejsze i lepiej powiązane z aktualnym stanem wiedzy, celowe wydaje się jego rozwinięcie o możliwość obliczania wskaźnika SVE_{DAS}, który bazuje na $H_{centerdist}$, a w badanej próbie wykazuje wyższą czułość na subtelne różnice kompozycyjne. Drugim narzędziem, opisywanym w ramach Publikacji VI, jest narzędzie do generowania kompozycji prostokątów, które stanowić może bazę dla narzędzia generującego całe elewacje. Narzędzie to pozwala określić zarówno parametry architektoniczne, takie jak liczba kondygnacji, wysokość kondygnacji, długość elewacji czy wymiary elementów kompozycyjnych, jak i typ kompozycji, zgodnie z typologią opisaną w Publikacji II, oraz docelowy stopień regularności wizualnej, opisany wskaźnikiem SVE_{DAS}. Oba wyżej opisane narzędzia mają charakter prototypowy, ale stanowią przekonujący dowód na aplikacyjne możliwości teoretycznych odkryć poczynionych w ramach cyklu sześciu artykułów, opisywanych w niniejszym autoreferacie.

Ważnym elementem ewaluacji, która była jednym z finalnych etapów projektu badawczego, było także poznanie preferencji estetycznych anonimowych uczestników badania ankietowego względem kompozycji fasad w odniesieniu do stopnia ich regularności. Badanie oraz jego wyniki szczegółowo opisano w Publikacji IV. Wyznaczono dość silny związek pomiędzy preferencjami estetycznymi a stopniem regularności wizualnej kompozycji – współczynnik Cohena f = 0,43 (Cohen 1988). Wyniki te, w połączeniu z innymi analizami statystycznymi opisanymi w Publikacji III, pozwalają na stwierdzenie, że w badanych próbach kompozycje bardziej regularne są uważane za bardziej estetyczne niż te mniej regularne. Stwierdzenie to jest zgodne z rezultatami innych badań, które jednak często wykraczają poza obszar architektury jako obszar badawczy. Można tu odnieść się do publikacji Pecchinendy i innych (2014), Taylora i innych (2003, 2005), Friedenberga (2021) czy też Bertaminiego i innych (2013).

Wyniki badań opisywanych w ramach niniejszego cyklu są szczególnie istotne w kontekście teorii Birkhoffa i Eysencka (Birkhoff 1936, Davis 1936, Eysenck 1941). Zgodnie z tą teorią, im bardziej obiekt jest regularny, a jego złożoność większa, tym jego wartość estetyczna jest większa. Teoria ta została już wielokrotnie potwierdzona zarówno w odniesieniu do architektury, jak i innych obiektów, przedmiotów czy obrazów (Alexander 2002, Douchova 2015, Mather i inni 2023, Staudek 1999). Opierając się na wyżej wzmiankowanej teorii oraz wynikach Publikacji IV niniejszego cyklu, można sformułować postulat, aby w projektowaniu elewacji rozważać rozwiązania o regularnych układach, przy jednoczesnym dążeniu do odpowiedniego poziomu złożoności. Wyniki badań wskazują, że takie kompozycje są – przeciętnie – postrzegane jako bardziej estetyczne w badanych próbach. Należy jednocześnie pamiętać, że współczesna architektura mieszkaniowa w praktyce często operuje językiem nieregularności estetycznej, co wskazano w Publikacji I, a rozbieżność pomiędzy tym językiem a preferencjami części użytkowników została już opisana w literaturze naukowej (Fawcett 1996, Frimpong i Dansoh 2018, Mertens i inni 2023).

Problem projektowania architektury mieszkaniowej, wielorodzinnej w kontekście spełnienia oczekiwań jej użytkowników jest naturalnie związany z tym, że ich potencjalni użytkownicy nie są znani na etapie projektowym. Ponadto powszechnie uważa się, że piękno i estetyka są kategoriami subiektywnymi, niemierzalnymi. Wyniki badań, zarówno tych autorskich, jak i literaturowych, przeprowadzonych w ramach projektu badawczego opisywanego w niniejszej rozprawie, sugerują jednak możliwość zastosowania nowego podejścia w kształtowaniu wyrazu estetycznego architektury wielorodzinnej. Bazując na opracowanej typologii kompozycji oraz wykorzystując wyznaczone w Publikacji V i VI wskaźniki regularności wizualnej kompozycji, przy jednoczesnej świadomości preferencji estetycznych wynikających z badania opisywanego w Publikacji IV oraz teorii Birkhoffa i Eysencka (Birkhoff 1936, Davis 1936, Eysenck 1941), możliwe staje się prognozowanie tendencji w ocenach estetycznych na poziomie zbiorowości, w populacjach zbliżonych do badanych, już na etapie projektu. Prognozy te nie zastępują jednak pełnych procesów partycypacyjnych ani nie uwzględniają całego spektrum indywidualnych różnic, lecz mogą stanowić dodatkową, ilościowo zdefiniowaną warstwę informacji wspierającą decyzje projektowe.

Ponadto, wykazana możliwość parametryzacji regularności, a dalej – estetyki architektury, otwiera potencjalnie drogę do wykorzystania tych parametrów w narzędziach planistycznych, a nawet – w dalszej perspektywie – w wybranych zapisach prawa miejscowego. Naturalnie byłoby to podejście eksperymentalne i obarczone ryzykiem nadmiernej normatywności, zwłaszcza w kontekście nowych, nieodkrytych jeszcze kierunków projektowych. Niemniej jednak takie podejście mogłoby być pomocne w budowaniu miast o bardziej spójnym charakterze przestrzennym. Wprowadzenie wskaźników regularności mogłoby wesprzeć myślenie o architekturze tła i dominantach już nie tylko w sensie funkcjonalnym i kubaturowym, ale także ilościowo opisanej kompozycji fasad. Ewentualne zastosowania tego rodzaju powinny jednak wynikać z szerokiej debaty eksperckiej i być poprzedzone dalszymi badaniami.

Wyżej zaproponowane podejście do projektowania architektury oznaczałoby także nowy wymiar partycypacji społecznej. Współczesna technologia, postępująca cyfryzacja różnych sfer życia społecznego oraz rosnące możliwości agregacji i przetwarzania danych tworzą szanse na poznanie preferencji społeczeństwa ogółem, jak i poszczególnych grup społecznych, względem potencjalnie wszystkich kluczowych elementów architektury. Taki sposób projektowania – w połączeniu z odpowiedzialnym planowaniem – mógłby wynieść architekturę mieszkaniową na inny poziom. Architekci mogliby tworzyć budynki, które nie tylko spełniałyby oczekiwania estetyczne użytkowników, ale byłyby lepiej dostosowane do nich np. pod kątem struktury mieszkań czy ich układów funkcjonalnych. Podchodząc do projektowania w taki sposób, projektanci są także w stanie lepiej uwzględniać potrzeby i oczekiwania osób ze szczególnymi potrzebami. Co ciekawe, tego rodzaju podejście od wielu lat jest wykorzystywane w badaniach z zakresu User Experience (UX) użytkowników produktów cyfrowych – stron internetowych czy aplikacji – i może stanowić inspirację dla procesów projektowania architektury.

Co ważne, bazowanie na preferencjach użytkowników – w tym estetycznych – nie musi wiązać się z obniżeniem jakości i wartości architektury, rozumianej jako dziedziny sztuki. Poznanie preferencji użytkowników czy też mechanizmów ich wyborów oznacza przede wszystkim określenie ram, w których twórca się porusza. Spełnianie szeregu wymagań, w tym prawnych, technicznych i użytkowych, jest wpisane w naturę architektury jako sztuki użytkowej.

Podsumowując, rozważne ograniczanie części swobody twórczej na rzecz poprawy jakości życia i zwiększenia stopnia zadowolenia użytkowników z ich miejsc zamieszkania wydaje się zasadne. Przy dużym deficycie mieszkaniowym, wysokim stopniu komercjalizacji sektora budownictwa mieszkaniowego i nastrojach społecznych wskazujących na niezadowolenie z warunków zamieszkania, architekci powinni w szczególności skupić się na poprawie jakości życia przyszłych mieszkańców polskich miast, przy jednoczesnym zachowaniu przestrzeni dla innowacji i różnorodności formalnej.

W tym miejscu warto syntetycznie wskazać główne ograniczenia badań, które wyznaczają zakres ważności przytoczonych wniosków. Po pierwsze, zasadniczy korpus analiz odnosi się do współczesnej architektury mieszkaniowej, wielorodzinnej w Polsce – nie badano systematycznie innych funkcji ani innych kręgów kulturowych. Po drugie, w analizach formalnych fasady sprowadzono do dwuwymiarowych kompozycji prostokątnych elementów, pomijając takie aspekty jak materiał, kolorystyka, głębia przestrzenna, detal czy kontekst urbanistyczny. Po trzecie, próby percepcyjne i preferencyjne były wyraźnie ograniczone i spełniały jedynie wartości minimalne dla badań o charakterze ogólnym dla całych społeczności. Po czwarte, wskaźniki $H_{centerdist}$ i SVE_{DAS} opracowano i przetestowano na zestawach kompozycji wyprowadzonych z ograniczonej liczby realizacji nominowanych do nagrody im. Miesa van der Rohe. Po piąte, zaprezentowane narzędzia cyfrowe mają charakter prototypowy i nie zostały jeszcze szeroko zweryfikowane w praktycznym workflow projektowym. Ograniczenia te nie unieważniają przedstawionych wyników, lecz jasno określają ich zakres obowiązywania i wskazują kierunki potrzebnych badań uzupełniających.

6. WNIOSKI KOŃCOWE

Podsumowując, w ramach cyklu sześciu artykułów naukowych, opisywanych na łamach niniejszego autoreferatu, zrealizowano – w przyjętym zakresie przedmiotowym i metodologicznym – zarówno główny, jak i szczegółowe cele pracy oraz udzielono odpowiedzi na wszystkie pytania badawcze. Zidentyfikowano nieregularność wizualną jako jedną z cech charakterystycznych współczesnej, polskiej architektury mieszkaniowej, wielorodzinnej. Ponadto potwierdzono tezę, że jedną z istotnych dróg realizacji owej nieregularności jest kompozycja fasad. W dalszej części wyabstrahowano i zdefiniowano sześć wzorów kompozycyjnych, którymi można opisać wszystkie kompozycje fasad współczesnych, polskich budynków mieszkalnych, wielorodzinnych w badanej próbie. Typologia ta może stanowić punkt wyjścia do weryfikacji w innych kontekstach funkcjonalnych i kulturowych, jednak wymaga dalszych badań przed sformułowaniem wniosków o charakterze uniwersalnym. W kolejnych etapach poddano ewaluacji wyznaczone typy kompozycji i – na podstawie badań ankietowych – wykazano korelację pomiędzy postrzeganą regularnością a typami wzorów, które są bardziej uporządkowane. Ponadto wykazano korelację pomiędzy regularnością wizualną (zarówno percepcyjną, jak i ilościowo opisaną) a konkretnymi typami wzorów z opracowanej typologii wzorów kompozycyjnych, co potwierdzono także badaniami in silico. W ramach badań wykazano również możliwość matematycznego obliczenia poziomu regularności kompozycji architektonicznej. Opracowano wskaźnik $H_{centerdist}$ oraz jego ulepszenie – SVE_{DAS}. Oba wskaźniki, bazujące na entropii Shannona, korelują z regularnością wizualną kompozycji na poziomie przekraczającym 90% w badanych zestawach kompozycji, a SVE_{DAS} w 96% przypadków prawidłowo porządkuje pary kompozycji pod kątem regularności. Ostatecznie zweryfikowano także możliwości aplikacyjne odkryć teoretycznych i opracowano dwa narzędzia cyfrowe – jedno do obliczania wskaźnika regularności wizualnej $H_{centerdist}$ kompozycji, drugie – do generowania kompozycji o zadanych parametrach architektonicznych, konkretnym typie kompozycji oraz poziomie regularności wizualnej.

Rezultaty teoretyczne wypływające z cyklu artykułów opisywanych w niniejszej rozprawie stanowią szansę na rozwój w zakresie nauczania projektowania architektonicznego, badań naukowych nad estetyką i typologią architektury historycznej oraz współczesnej, a także badań nad percepcją architektury. Mogą one również stanowić punkt wyjścia dla kształtowania się dyskursu w architekturze bardziej nakierowanego na użytkownika i jego doświadczenia, przy jednoczesnym zachowaniu świadomości ograniczeń ilościowych ujęć estetyki.

Równie istotne są implikacje wypływające z rezultatów praktycznych. Zdefiniowana typologia kompozycji oraz wskaźniki opisujące regularność wizualną kompozycji posiadają istotny potencjał aplikacyjny w odniesieniu do procesu projektowego – zarówno po stronie projektantów, jak i urbanistów wyznaczających ramy zagospodarowania przestrzennego, czy sędziów konkursowych. Możliwość ilościowego przedstawienia regularności kompozycji to z jednej strony metoda na uzasadnienie przyjętej estetyki w sposób oparty na mierzalnych parametrach, z drugiej zaś – potencjalne narzędzie opisu oczekiwań planistów w zakresie kompozycji fasad oraz metoda walidacji zastosowanych rozwiązań projektowych.

Matematyczna kodyfikacja wybranego aspektu estetyki fasady daje szerokie możliwości zastosowania efektów cyklu opisywanego w niniejszej rozprawie w narzędziach do projektowania architektonicznego i – po odpowiednich pracach wdrożeniowych – może stać się podstawą rozwiązań o potencjale komercyjnym.

Wnioski wypływające z cyklu publikacji opisywanych na łamach niniejszej rozprawy stanowią również podwaliny pod dalsze badania. Szczególnie istotne wydaje się zweryfikowanie możliwości odniesienia poczynionych odkryć do architektury o innej funkcji niż mieszkaniowa wielorodzinna, np. biurowej czy usługowej, a także w odniesieniu do innych kręgów kulturowych – poza Polską. Ważne jest także poszerzenie badań związanych z preferencjami estetycznymi. Badania przeprowadzone w ramach cyklu opisywanego w niniejszej rozprawie miały charakter ogólny, bez wyszczególnienia podgrup badawczych. Poszerzenie próbek badawczych i zweryfikowanie preferencji w odniesieniu do różnych grup wiekowych, społeczno-ekonomicznych, geograficznych, a także płci z pewnością dostarczyłoby bardziej szczegółowe dane i pozwoliłoby jeszcze lepiej odpowiadać na potrzeby użytkowników.

Wątpliwości budzi także pewien rozdźwięk, który pojawia się w obrębie samego pojęcia regularności. Z jednej strony dowiedziono, że regularność wpływa pozytywnie na doznania estetyczne odbiorcy, z drugiej zaś – może wiązać się z monumentalnością czy przytłaczającą powtarzalnością wizualną. Bez wątpienia badania, które pozwoliłyby lepiej zrozumieć granicę pomiędzy pozytywnym i negatywnym wpływem regularności na estetykę architektury, byłyby bardzo cenne. W tym kontekście szczególnie obiecujące wydają się badania łączące metody ilościowe z obserwacją zachowań użytkowników w rzeczywistych przestrzeniach oraz z pomiarami psychofizjologicznymi.

Opracowane współczynniki regularności kompozycji oraz typologia kompozycji, choć mogą stanowić wyraźne wskazówki dla projektantów, zdecydowanie nie powinny być traktowane jako jedyne przesłanki w podejmowaniu decyzji projektowych. W badaniach skupiono się jedynie na fragmencie estetyki architektonicznej oraz jej percepcji – konkretnej relacji między regularnością/nieregularnością prostokątnych kompozycji fasad a ich odbiorem – i ten fragment opisano. Pozostałe aspekty, takie jak materiał, kolor, detal, relacja z kontekstem urbanistycznym czy znaczenie społeczne i kulturowe, nadal wymagają pogłębionych badań i refleksji projektowej.

7. PIŚMIENNICTWO

Alexander, C. 1977. *A Pattern Language: Towns, Buildings, Construction*. Oxford: Oxford University Press.

Alexander, C. 2002. *The Nature of Order: The Phenomenon of Life*. Berkeley: Center for Environmental Structure.

Alberti, L.B. 1960. *Ksiąg dziesięć o sztuce budowania*. Warszawa: Państwowe Wydawnictwo Naukowe.

Amir, O.; Biederman, I.; Hayworth, K.J. 2011. "The neural basis for shape preferences." *Vision Research*, 51, 2198–2206. DOI: 10.1016/j.visres.2011.08.015.

Baumeister, R.F. 1999. "The self." *Psychological Review*, 106(2), 323–352. DOI: 10.1037/1089-2680.5.4.323.

Bertamini, M.; Makin, A.; Rampone, G. 2013. "Implicit association of symmetry with positive valence, high arousal and simplicity." *i-Perception*, 4, 317–327. DOI: 10.1068/i0601JW.

Biederman, I. 1987. "Recognition-by-components: A theory of human image understanding." *Psychological Review*, 94(2), 115–147. DOI: 10.1037/0033-295X.94.2.115.

Cohen, J. 1988. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates.

Coulton, J.J. 1975. "Towards understanding Greek temple design: General considerations." *Annual of the British School at Athens*, 70, 59–99.

Davis, R.C. 1936. "An evaluation and test of Birkhoff's aesthetic measure formula." *Journal of General Psychology*, 15, 231–240.

Douchová, V. 2015. "Birkhoff's aesthetic measure." *Acta Universitatis Carolinae – Philosophica et Historica*, 1, 39–53.

Dyckhoff, T. 2018. *Epoka spektaklu: Perypetie architektury i miasta XXI wieku*. Tłum. A. Rasmus-Zgorzelska. Kraków: Wydawnictwo Karakter.

Eysenck, H. 1941. "The empirical determination of an aesthetic formula." *Psychological Review*, 48, 83–92.

Evans, J.D. 1996. *Straightforward Statistics for the Behavioral Sciences*. Pacific Grove, CA: Brooks/Cole Publishing.

Fawcett, W. 1996. "Architecture: Functional approach or the case for user research." *Architectural Research Quarterly*, 1(3), 8–15.

Friedenberg, J.E.A. 2021. "Judged beauty of fractal symmetries." *Empirical Studies of the Arts*, 40, 1–19.

Frimpong, S.; Dansoh, A. 2018. "The marginalization and invasion of architects' role on house projects: Institutional intervention inadequacy and super wicked problems." *Frontiers of Architectural Research*, 7(3), 292–303.

Guiaşu, S. 1971. "Weighted entropy." *Reports on Mathematical Physics*, 2(3), 165–179. DOI: 10.1016/0034-4877(71)90002-4

Garde, A.M. 2020. "New urbanism: Past, present, and future." *Urban Planning*, 5(4), 453–463. DOI: 10.17645/up.v5i4.3478.

Garnier, T. 1990. *Une Cité Industrielle*. Ed. R. Mariani. New York: Rizzoli.

Howard, E. 1965. *Garden Cities of To-morrow*. Ed. F.J. Osborn. Cambridge, MA: MIT Press. (First published 1902).

Huemer, W.; Vendrell Ferran, Í. 2018. "Introduction: The place of beauty in contemporary aesthetics." In: *The Place of Beauty in Contemporary Aesthetics*, 1–15. PhilArchive.

Ilgaz, E. E.; Bittermann, M. S.; Özkan, D. Y. 2025. “On the regularity of opening patterns in building facades.” *Nexus Network Journal*, 27(2), 373–389. DOI: 10.1007/s00004-025-00815-1

Jenkins, S. 2024. "The ransacking of Britain: Why the people finally rose up against ‘sod-you architecture’." *The Guardian*, 28 Oct. 2024. https://www.theguardian.com/culture/2024/oct/28/ransacking-britain-sod-you-architecture-corbusier.

Kawabata, H.; Zeki, S. 2004. "Neural correlates of beauty." *Journal of Neurophysiology*, 91, 1699–1705.

Krier, R. 1988. *Architectural Composition*. New York: Rizzoli.

Le Corbusier. 1968. *Towards a New Architecture*. Trans. F. Etchells. London: Architectural Press. (Originally published 1923 as *Vers une architecture*).

Light, A.; Smith, J.M., eds. 2005. *The Aesthetics of Everyday Life*. New York: Columbia University Press.

Mandoki, K. 2007. *Everyday Aesthetics: Prosaics, the Play of Culture and Social Identities*. Aldershot: Ashgate. DOI: 10.4324/9781315581286.

Mather, K.B.; Aleem, H.; Rhee, Y.; Grzywacz, N.M. 2023. "Social groups and polarization of aesthetic values from symmetry and complexity." *Scientific Reports*, 13, 21507.

Maslow, A.H. 2006. *Motywacja i osobowość*. Tłum. A. Jankowski. Warszawa: Wydawnictwo Naukowe PWN. (Originally 1954).

Med’dahi, K; Boussora, H. 2021. „Parametric description of facade order using Eysenck’s method.” *Nexus Network Journal*, 23(3), 667–688. DOI: 10.1007/s00004-021-00546-z

Mertens, A.; Hamarat, Y.; Elsen, C. 2023. "Interactions between architects and end-users during housing design processes: A systematic literature review." *Archnet-IJAR*, 17(4), 703–724. DOI: 10.1108/ARCH-03-2022-0079.

Ministerstwo Rozwoju i Technologii. 2020. *Raport o stanie mieszkalnictwa* [online]. https://www.gov.pl/web/rozwoj/raport-o-stanie-mieszkalnictwa.

Montañana, J.; Llinares, C.; Navarro, J. 2013. "Architects and non-architects: Differences in perception of property design." *Journal of Housing and the Built Environment*, 28(3), 389–402. DOI: 10.1007/s10901-013-9337-1.

Neufert, E. 2022. *Podręcznik projektowania architektoniczno-budowlanego*. Tłum. K. Żak. Warszawa: Wydawnictwo Arkady.

Niebrzydowski, W. 2021. "The impact of avant-garde art on brutalist architecture." *Buildings*, 11(7), 290. DOI: 10.3390/buildings11070290.

Omale, R.P. 2022. "Evaluation of aesthetic perceptions of public buildings' façades by design professionals." *Edinburgh Architecture Research*, 37, 70–81. DOI: 10.2218/ear.2022.7802.

Pecchinenda, A.; Bertamini, M.; Makin, A.D.J.; Ruta, N. 2014. "The pleasantness of visual symmetry: Always, never or sometimes." *PLoS ONE*, 9, e92685. DOI: 10.1371/journal.pone.0092685.

Rosner, V. 2020. *Machines for Living: Modernism and Domestic Life*. Oxford: Oxford University Press.

Saito, Y. 2007. *Everyday Aesthetics*. Oxford: Oxford University Press. DOI: 10.1093/acprof:oso/9780199278350.001.0001.

Saito, Y. 2007. "The moral dimension of Japanese aesthetics." *The Journal of Aesthetics and Art Criticism*, 65(1), 85–97. DOI: 10.1111/j.1540-594X.2007.00240.x.

Safarova, K.; Pirko, M.; Jurik, V. 2019. "Differences between young architects' and non-architects' aesthetic evaluation of buildings." *Frontiers of Architectural Research*, 8(2), 229–237. DOI: 10.1016/j.foar.2019.04.001.

Sartwell, C. 1995. *The Art of Living: Aesthetics of the Ordinary in World Spiritual Traditions*. Albany: State University of New York Press.

Schwarte, L. 2014. "Performative architecture: Setting a stage for political action." *Pavilion Magazine* [online]. https://www.pavilionmagazine.org/ludger-schwarte-performative-architecture-setting-a-stage-for-political-action/.

Stewart, I. 2007. *Why Beauty Is Truth: A History of Symmetry*. New York: Basic Books.

Stiny, G; Mitchell, J. W. 1978. "The Palladian grammar." *Environment and Planning B: Planning and Design*, 5(1), 5–18.

Surówka, M. 2018. "Deficyt mieszkaniowy jako główny problem polskiego mieszkalnictwa." *Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania*, 52, 119–129.

Taylor, R.; Newell, B.; Spehar, B.; Clifford, C. 2005. "Fractals: A resonance between art and nature." In: Emmer, M. (ed.) *Mathematics and Culture II*. Berlin: Springer, 53–63. DOI: 10.1007/3-540-26443-4_6.

Taylor, R. 2003. "Fractal expressionism – where art meets science." In: Casti, J.; Karlqvist, A. (eds.) *Art and Complexity*. Atlanta, GA: JAI Press.

Trębacz, P; Mazur, R. 2020. "Typologia zabudowy mieszkaniowej wielorodzinnej w Polsce w latach 2010-2019." *Środowisko Mieszkaniowe*, 30, 37-46. DOI: 10.4467/25438700SM.20.004.12207

Tuan, Y.F. 1974. *Topophilia: A Study of Environmental Perception, Attitudes, and Values*. Englewood Cliffs, NJ: Prentice-Hall.

Ulman, P.; Ćwiek, M. 2020. "Measuring housing poverty in Poland: a multidimensional analysis." *Housing Studies*, 36(8), 1212-30, DOI: 10.1080/02673037.2020.1759515

Upton, D. 2002. "Architecture in everyday life." *New Literary History*, 33(4), 707–723. DOI: 10.1353/nlh.2002.0046.

Vermeulen, T.; van den Akker, R. 2010. "Notes on metamodernism." *Journal of Aesthetics & Culture*, 2, 5677. DOI: 10.3402/jac.v2i0.5677.

Walker, R. 2008. *Buying In: The Secret Dialogue Between What We Buy and Who We Are*. New York: Random House.

Witruwiusz. 1956. *O architekturze ksiąg dziesięć*. Tłum. K. Majewski, J. Żurowski. Warszawa: Państwowe Wydawnictwo Naukowe.

Zeki, S. 1999. *Inner Vision: An Exploration of Art and the Brain*. Oxford: Oxford University Press.

8. OŚWIADCZENIA WSPÓŁAUTORÓW PRAC

Ja, niżej podpisany, prof. dr hab. inż. arch. Antoni Taraszkiewicz, oświadczam, że jestem współautorem publikacji pt.:

„Composition Patterns of Contemporary Polish Residential Building Facades.”, opublikowanej w 2022 roku w czasopiśmie Nexus Network Journal, nr DOI: 10.1007/s00004-022-00614-y,

„Preferences of the Facade Composition in the Context of Its Regularity and Irregularity.”, opublikowanej w czasopiśmie Buildings, nr DOI: 10.3390/buildings12020169,

oraz

„Visual Perception of Regularity and the Composition Pattern Type of the Facade.”, opublikowanej w 2024 roku w czasopiśmie Buildings, nr DOI: 10.3390/buildings14051389,

wchodzących w skład cyklu publikacji stanowiących podstawę rozprawy doktorskiej Pana mgr inż. arch. Michała Malewczyka.

Mój udział w powstawaniu tych publikacji obejmował następujące czynności naukowe:

1. Współuczestnictwo w kształtowaniu koncepcji badawczej, w szczególności poprzez udział w dyskusjach dotyczących zakresu merytorycznego oraz kierunku interpretacji problematyki podjętej w pracy.
2. Merytoryczną konsultację manuskryptu na etapie formułowania założeń oraz opracowywania części teoretycznej publikacji.
3. Recenzyjne wsparcie wewnętrzne, obejmujące zgłaszanie sugestii, komentarzy i propozycji udoskonaleń tekstu, mieszczących się w standardach pracy zespołowej nad publikacją naukową.

Oświadczam, że powyższy wkład odpowiada zasadom rzetelności naukowej i uzasadnia moje współautorstwo. Jednocześnie potwierdzam, że zasadnicza część badań, analiz, interpretacji wyników oraz opracowania manuskryptu została wykonana przez doktoranta – zgodnie z wymaganiami przewidzianymi dla rozprawy doktorskiej przygotowanej w formie cyklu publikacji.

Ja, niżej podpisany, dr inż. arch. Piotr Czyż, oświadczam, że jestem współautorem publikacji pt.:

„Features of irregularity in examples of Polish multi-family architecture constructed in 2011–2021 and nominated for the Mies van der Rohe award.", opublikowanej w 2022 roku w czasopiśmie Czasopismo Techniczne, nr DOI: 10.37705/techtrans/e2022009,

„Composition Patterns of Contemporary Polish Residential Building Facades.", opublikowanej w 2022 roku w czasopiśmie Nexus Network Journal, nr DOI: 10.1007/s00004-022-00614-y,

„Preferences of the Facade Composition in the Context of Its Regularity and Irregularity.", opublikowanej w czasopiśmie Buildings, nr DOI: 10.3390/buildings12020169,

oraz

„Visual Perception of Regularity and the Composition Pattern Type of the Facade.", opublikowanej w 2024 roku w czasopiśmie Buildings, nr DOI: 10.3390/buildings14051389,

wchodzących w skład cyklu publikacji stanowiących podstawę rozprawy doktorskiej Pana mgr inż. arch. Michała Malewczyka.

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9. AKTYWNOŚĆ ORAZ DOROBEK NAUKOWY AUTORA

9.1 PROFIL NAUKOWY I GŁÓWNA TEMATYKA BADAWCZA

Aktywność naukowa autora niniejszej rozprawy koncentruje się na interdyscyplinarnym obszarze badań, łączącym zagadnienia geometrii, percepcji wizualnej i narzędzi cyfrowych stosowanych w architekturze. W centrum zainteresowań badawczych znajduje się kwantyfikacja cech formalnych obiektów architektonicznych oraz ich wpływu na odbiór użytkowników. Szczególne miejsce zajmuje rozwój metryk opisujących regularność i złożoność geometryczną elewacji — w tym wskaźników opartych na entropii metrycznej i analizie zmienności — oraz ich integracja z narzędziami obliczeniowymi umożliwiającymi praktyczne zastosowanie tych metod w procesach projektowych.

Prace autora wpisują się w szerszy nurt cyfryzacji analizy architektonicznej, obejmując zarówno rozwój teoretycznych podstaw pomiaru regularności kompozycji, jak i implementację tych narzędzi w środowisku Blender/Python. Istotne miejsce w działalności naukowej zajmuje również powiązanie badań geometrycznych z celami zrównoważonego rozwoju, zwłaszcza w kontekście jakości środowiska zabudowanego (SDG 11). Oś tych badań stanowi cykl publikacji przedstawionych w niniejszej rozprawie, obejmujący autorskie narzędzia, metody i analizy dotyczące strukturalnych właściwości architektury mieszkaniowej.

9.2 DOROBEK PUBLIKACYJNY

Dorobek publikacyjny autora obejmuje dziewięć prac, w tym trzy artykuły wyłącznego autorstwa. Z tego osiem zostało opublikowanych w recenzowanych czasopismach naukowych ujętych w wykazie Ministerstwa Edukacji i Nauki, natomiast pozostała praca została udostępniona jako preprint. Sześć artykułów składających się na cykl niniejszej rozprawy przedstawia spójny i stopniowy rozwój autorskich metod analitycznych oraz narzędzi wspomagających projektowanie. Każda z publikacji wnosi odrębny element do całości dorobku — od dopracowania definicji wskaźników, przez analizę przypadków i porównania metodologiczne, aż po demonstrację ich użyteczności w praktyce projektowej. Zgromadzony dorobek publikacyjny dokumentuje rozwój linii badawczej autora oraz rozwój narzędzi cyfrowych stosowanych w analizie architektury.

9.3. AKTYWNOŚĆ ORGANIZACYJNA I INNE FORMY ZAANGAŻOWANIA

Autor wykazuje aktywność w środowisku naukowym, uczestnicząc w organizacji wydarzeń o charakterze międzynarodowym. Był współorganizatorem „Pavia Digi Week 2022" oraz współprowadzącym seminarium i warsztaty „HBIM for Architectural Management", realizowane we współpracy z Universitat Politècnica de València, University of Pavia oraz Universidad Nacional de Córdoba w dniach 19–23 września 2023 r. Jego wkład obejmował przygotowanie części programowej, prowadzenie zajęć oraz konsultacje dotyczące zastosowania narzędzi cyfrowych w analizie i dokumentacji architektonicznej.

Autor uczestniczy także w procesach recenzyjnych publikacji naukowych, współpracując z czasopismami z obszaru badań nad cyfryzacją architektury i urbanistyki.

Zaangażowanie to stanowi istotny element aktywności akademickiej i wiąże się z krytyczną oceną dorobku naukowego innych badaczy.

9.4 AKTYWNOŚĆ DYDAKTYCZNA ZWIĄZANA Z TEMATYKĄ BADAŃ

W ramach działalności dydaktycznej autor prowadził zajęcia na kierunkach Architektura oraz Gospodarka Przestrzenna na Wydziale Architektury Politechniki Gdańskiej. Wśród realizowanych kursów znajdują się m.in.: Techniki informacyjne CAD, Techniki komputerowe, Grafika inżynierska, Geometria wykreślna oraz Geometria dla architekta. Autor prowadził wykłady, ćwiczenia i projekty zarówno w języku polskim, jak i angielskim, obejmując różne poziomy zaawansowania studentów.

W działalności dydaktycznej autor wykorzystuje zarówno kompetencje w zakresie obsługi narzędzi cyfrowych, jak i doświadczenia wynikające z własnych badań naukowych. Jest autorem cyfrowej transformacji kursów „Geometria wykreślna" oraz „Geometria dla architekta", obejmującej m.in. wprowadzenie nowoczesnych metod wizualizacji, ćwiczeń interaktywnych oraz stworzenie autorskiej platformy geometria-pg.org do nauczania geometrii wykreślnej. Opracowane materiały dydaktyczne oraz sposób prowadzenia zajęć odzwierciedlają doświadczenia zdobyte podczas badań nad geometryczną analizą architektury, co pozwala integrować klasyczne zagadnienia geometrii z aktualnymi narzędziami cyfrowymi i zwiększać ich użyteczność w praktyce projektowej. Proces kształcenia zyskuje dzięki temu charakter nowoczesny, spójny z rozwojem technologii i odpowiadający potrzebom współczesnej edukacji architektonicznej.

9.5 WSPÓŁPRACA Z OTOCZENIEM SPOŁECZNO-GOSPODARCZYM

Autor posiada wieloletnią praktykę zawodową w obszarze projektowania architektonicznego, obejmującą pracę na stanowiskach konsultanta, asystenta architekta oraz architekta prowadzącego. W projektach realizowanych we współpracy z biurami projektowymi oraz w ramach własnej działalności zawodowej wdraża rozwijane narzędzia oraz metody badawcze, szczególnie w zakresie analiz geometrycznych, optymalizacji projektów mieszkaniowych oraz systematyzacji układów elewacyjnych.

Praktyczne zastosowanie wyników badań obejmuje m.in. wykorzystanie autorskich metryk entropii i zmienności do wspomagania decyzji projektowych, opracowywanie narzędzi cyfrowych usprawniających procesy modelowania oraz analizowanie fasad w kontekście jakości środowiska zabudowanego. W rezultacie prowadzona działalność naukowa znajduje bezpośrednie przełożenie na praktykę architektoniczną i jest ukierunkowana na odpowiadanie na rzeczywiste potrzeby branży.