An Analysis of Learning Landscapes

Lessons Learned for a National Movement

December 2023

Autocase
Economic Advisory

BIG SANDBOX
building healthy neighborhoods

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Grant Report

Prepared For
The Children & Nature Network

Prepared By

Big Sandbox — building healthy neighborhoods

Autocase Economic Advisory

PROJECT TEAM

The multi-sectoral and multidisciplinary team includes: Autocase™ (created by Impact Infrastructure) and their professionals across North America who are known for best-practice cost-benefit analysis approaches and tools that involve all facets of infrastructure development; Professor Lois Brink with 20 years of experience with the implementation and research of Learning Landscapes (LL); Peter Anthamatten, fellow LL researcher and Chair of Geography and Environmental Sciences at University of Colorado Denver supporting data analyses from the previous NIH & RWJF grants. Peter and Lois have co-authored papers on LL and the results from RWJF & NIH grants; and, Josh Griesbach, senior facility planner with DPS. Josh was our POC with the district.

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ACKNOWLEDGMENTS

Additional support provided by the Denver Public School District.
Thank you for your guidance and sharing information included in this report.

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The project team is grateful for the valuable information and insights provided by staff at the Colorado Department of Education.

Cover photo: Harrington Elementary Banners 2012

learning landscapes
building community through play

Contents

1. Executive Summary

Schools are vital infrastructure for healthy, flourishing communities, and are essential to improving quality of life for city residents. In this report, Autocase, the Big SandBox and the Children and Nature Network, in partnership with Denver Public Schools (DPS), used a statistical regression analysis to determine actual outcomes using quantitative data from DPS and the Colorado Department of Education to determine benefits of the Learning Landscapes (LL) program, a large scale green schoolyard conversion project. From 2000 to 2012, Denver Public Schools (DPS) converted 99 elementary schoolyards encompassing 306 acres to Learning Landscapes. This report leverages empirical data to evaluate and generate quantitative insights on outcomes of green schoolyard projects. Results from the economic benefits analysis suggest that Learning Landscapes provide the following benefits:

Learning

- **7% statistically significant decrease in student mobility rate** which is equivalent to cutting the district wide elementary school student mobility rate by as much as one-third.
- **8.5% statistically significant increase in math growth annually.**
- **5.4% statistically significant increase in writing growth annually.**
- **.12% statistically significant increase in student performance framework annually.**
- **.01% statistically significant reduction in the truancy rate annually,** which is equivalent to over 700 less unexcused absence days.

Economics

- **An annual average of $1,341,777 revenue increase** in state funding for 152 new students enrolled. Increase student enrollment is evident in both the longitudinal and cross sectional analyses.
- **Learning Landscapes cost $630,012(ave.) or $2.54 sq. ft. ($2022)** New funding from voter-approved general obligation bonds account for 80% of LL funding and the remainder is from public/private partnerships.
- **Leveraging funds — Every $1 spent on a Learning Landscape $25** were realized for much needed deferred capital projects and education needs. Anecdotal evidence suggest LL is a highly visible and popular project among voters.

Environment

- **15 degree reduction in the average ambient temperature during summer months** due to increased tree canopy and vegetation.
- **1,284 tons of carbon sequestered annually across all converted schoolyards.**
- **404 lbs of air pollutants removed annually across all converted schoolyards.**

Each of these contribute to climate change adaptation and resilience and stronger community health.

Students' garden at Steck Elementary. Source UCD.

Health & Wellness

- **Learning Landscapes catalyst for district farms.** By 2012, LL's were at every elementary school and DPS launched its farm program. Farm annual revenue averaged $85,000 from 2012 — 2017.

- **Over 55% of Learning Landscapes have school gardens.** In 2012, only 10% of schools had gardens. With growing awareness around fresh produce, the district installed a salad bar at every school that same year. In 2022, **12,250 lbs of produce was donated.**

- **13 Learning Landscapes have a garden to cafeteria program.** Student-grown vegetables are sold to their cafeteria. Revenue in 2019 was $321/ school. These funds are used by students to sustain their gardens.

These significantly positive findings demonstrate the tipping point a green schoolyard can have when scaled across a district. DPS is an enthusiastic partner on this project. The district has a vested interest in understanding the impact of the Learning Landscapes as it continues to secure maintenance funds internally to sustain its green schoolyards.

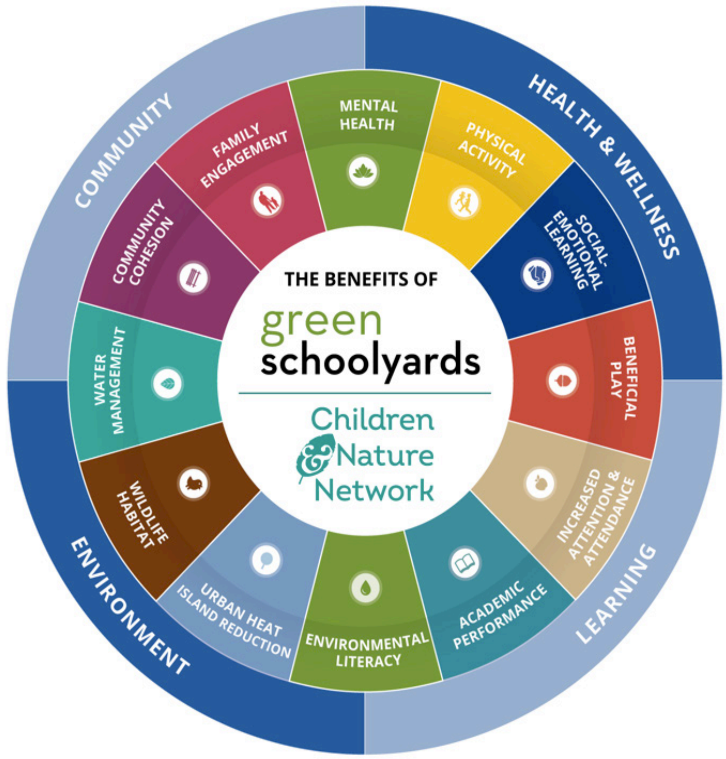
Learning Landscapes are an asset that benefits the broader community and are included as "breathing spaces" in Denver's Parks and Recreation Master Plan. By creating a shared understanding of the economic, social, and community value of green schoolyards, stakeholders within the community, district, and state can advocate for and integrate green schoolyards into capital planning and budgeting processes.

Pre and Post Schoolyard Photos of McGlone Elementary Learning Landscapes

2. Introduction

2.1 Background/Overview

The Children and Nature Network (C&NN) defines green schoolyards as multi-functional school grounds designed for and by the entire school community that include places for students, teachers, parents, and community members to play, learn, explore, grow, and connect. During the out-of-school time, these schoolyards are ideally open for community use. Green schoolyards might include outdoor classrooms, native and pollinator gardens, stormwater capture, nature play areas, traditional play equipment, edible gardens, trails and paths, trees and shrubs, and more[1].



Source: Children & Nature Network

This platform serves as the project's launch point for analyzing Learning Landscapes's (LL) economic benefits. The LL program, completed in 2012, is a district-wide schoolyard greening project (99 K-8 schoolyards) in the Denver public school system. These impacts can be sorted into occupant (students and staff) and community (neighborhood, municpality, and climate) impacts.

An initial literature review and an inter and intra-district economic benefits valuation determined the range of outcomes and potential "data buckets". This was followed by data collection and statistical analysis. The value of this undertaking is leveraging empirical data and generating quantitative insights to support scaling the development of green schoolyards across the country.

The research questions for this analysis are:

1. What quantifiable economic outcomes related to LL's are statistically significant?

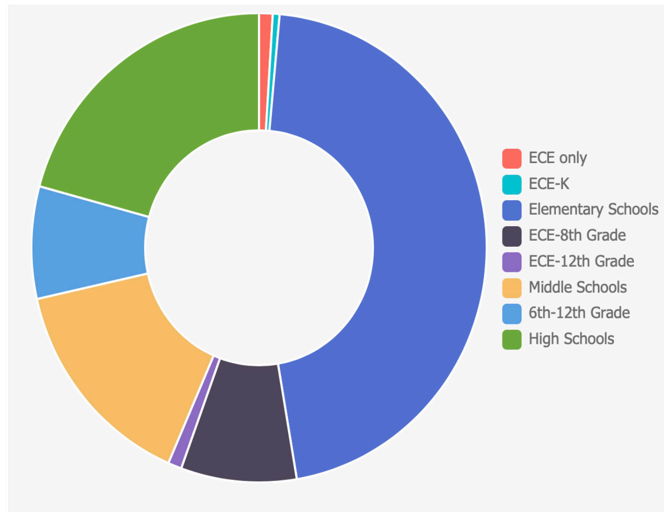
2. What are the long-term implications of schoolyard greening interventions on student outcomes and health and well-being ?

3. What quantitative/deterministic analysis can be conducted from the additional data gathered during this project?

2.2 Study Focus - Learning Landscapes

Denver Public Schools' district boundaries align with the city and county of Denver and is home to 90,250 students (October 2021). Facility Management maintains over 16 million square feet of enclosed building space at 207 schools, and just under 2,000 acres. As is illustrated below, the majority of the schools are elementary.

Breakdown of Student Population by Grade



Source: Denver Public Schools Website. 2023

DPS Pupil membership includes 72% English language learners (primarily Spanish-speaking students) with 59% of students eligible for Free/Reduced-Price Lunch. Gifted and Talented students account for 8% of the student body and students with disabilities make of up 12%. (DPS)

Learning Landscape schoolyards challenge the concept of traditional schoolyards with designs reflecting the unique culture and history of the people, the school, and the neighborhood it serves while providing opportunities for physical activity, socialization and creative play. On Learning Landscape schoolyards, students interact with educational elements such as fractions, historical timelines, common words, and quotes to help students learn as they play. Learning Landscape schoolyards are neighborhood parks used by the community on weekends and after school. The community is involved in all phases of development, building and stewardship of the Learning Landscape. The many people participating in Learning Landscape projects sends the essential message to the children and families of each community "We believe in you!"

Distinctive Elements of LL Schoolyards:

- Community gateways and gathering spaces with custom shade structures

- Colorful structured & unstructured asphalt games

- Age-appropriate play equipment

- Outdoor classroom and STEM elements

- Grass playing fields

- Public & student art

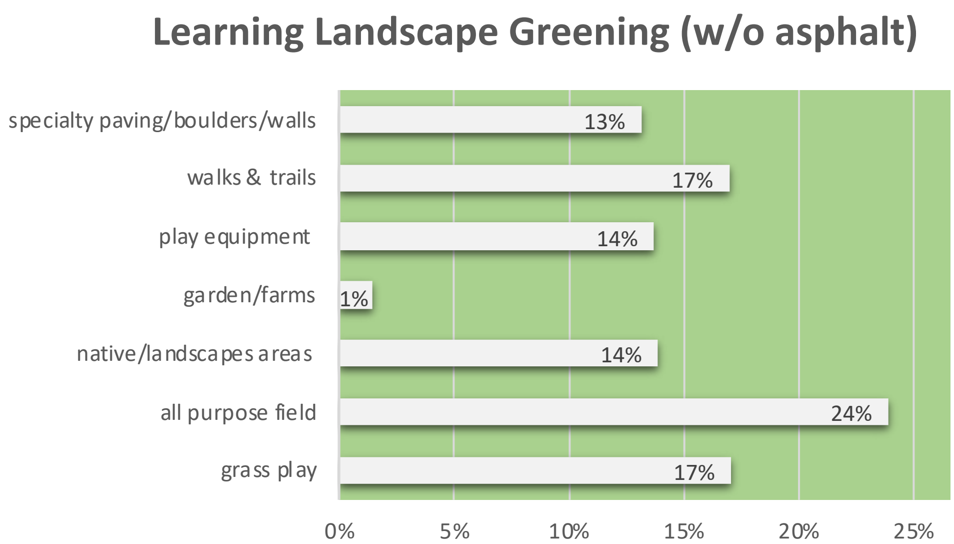
- Vegetable gardens

- Habitat areas/nature play

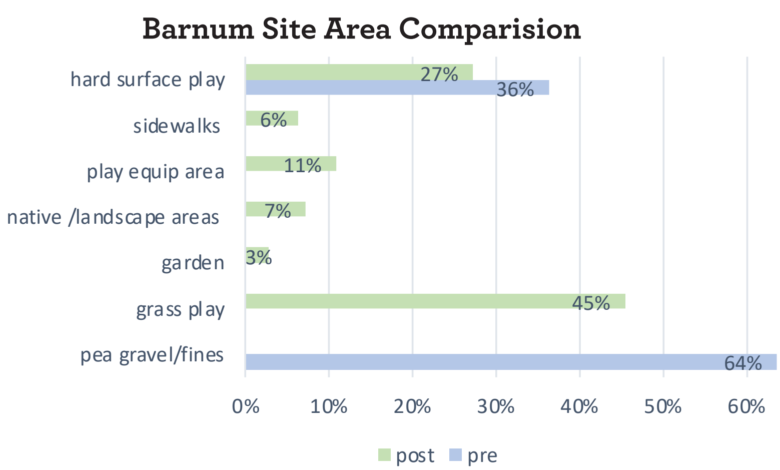
Students reading in their outdoor classroom at Harrington Elementary. 2012. Credit UCD

The LL district-wide schoolyard greening project encompasses 306 acres. Prior to Learning Landscape conversions, surfaces categorized as impervious or hard comprised 90% of an average schoolyard; pervious or soft surfaces comprised 10.2%.

After the conversions, the average pervious vegetative surfaces comprised 51% of an average schoolyard, pervious or soft surface 18%, while impervious or hard surface comprised only 31%.

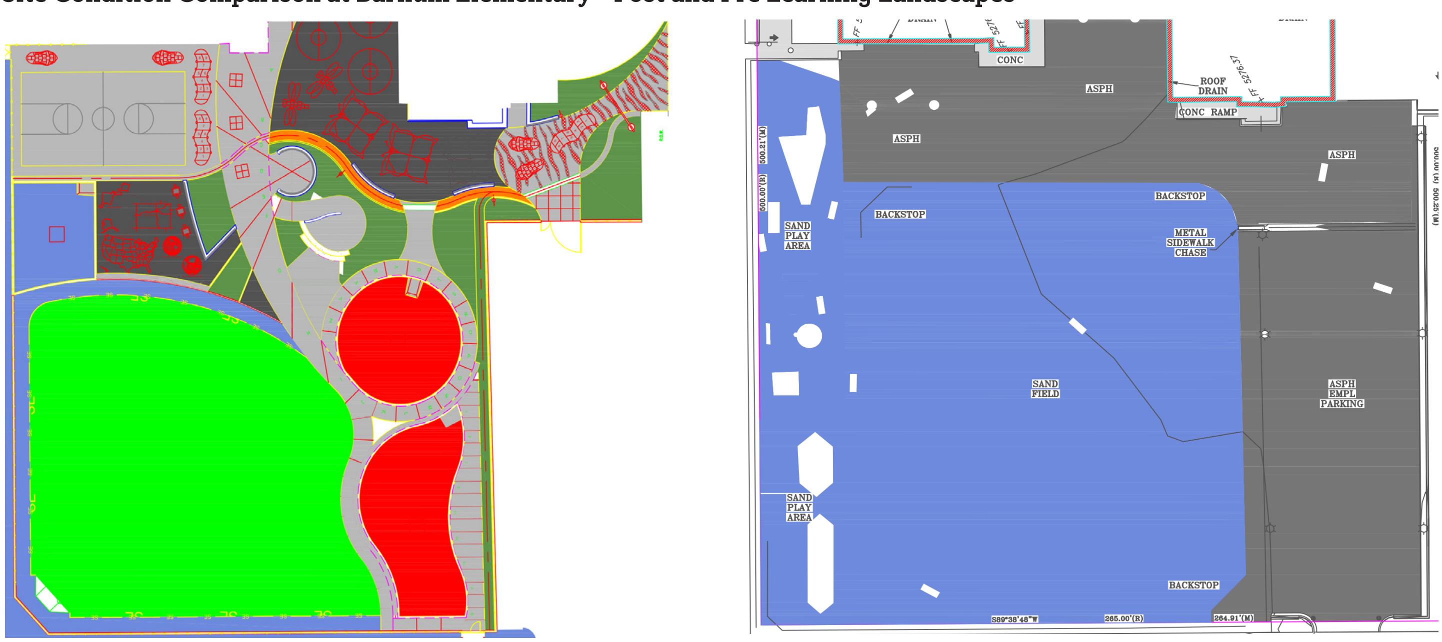


The chart to the right illustrates the breakdown of pervious conditions and the chart below illustrates the Barnum Elementary pre and post site area as example of a typical DPS schoolyard.



Funding for LLs occurred in three phases. In 2000, a public private entrepreneurial three-year campaign was launched raising a total of $9 million, improving 22 schoolyards, and generating significant political support. In response to this demand, the Denver Public School Board proposed two bond measures to expand Learning Landscapes to every elementary schoolyard in Denver. The 2003 bond measure included $10 million and the 2008 bond measure included $29 million.

Site Condition Comparison at Barnum Elementary - Post and Pre Learning Landscapes



3. Process

3.1 Literature Review

The Web of Science, Children & Nature Network Research Library, and Google Scholar were used to conduct searches for literature using key terms related to the targeted outcomes for Learning Landscapes. A list of 33 papers of interest were chosen for inclusion as examples of the state of the literature. The papers reviewed were selected according to the presence of quantitative and statistical analyses, in order to find gaps that could be filled with the subsequent econometric analysis. (See Appendix A for the full literature review.)

This review suggests that there is broad evidence to support the impact of schoolyard improvements on learning outcomes, but specific outcomes are lacking in research. Importantly, dropouts, enrollment, and unemployment are not commonly tied to schoolyard improvements in the literature. There is a good amount of literature on health and wellness outcomes, especially pertaining to increased play resulting from changes to the physical nature of schoolyards. Important gaps are the uncertain relationship between nutrition and school gardens, persistence of impacts into the future, and increases in school lunch sales.

Understudied Impacts
Some particular outcomes that have not been studied heavily that are important to quantify include:
- Effects of schoolyard improvements on enrollment rates and dropout rates
- Direct impacts on school lunch sales
- Absenteeism
- Principal referrals

Test Scores and Mental Health Improvements
Broad consensus has not been reached in the literature, making it important to evaluate directly as part of an econometric analysis. While these effects have been measured at length in the past, it will provide value to model them in this specific context for the benefit of local stakeholders and policy makers.

Community Outcomes
This represents the largest gap in the literature, including very little in the way of quantitative or statistical analysis.

A short list of C&NN outcomes were identified based on the opportunity for quantitative and statistical analyses. The table to the right reflects the four major categories and further delineates the outcomes accordingly.

C&NN OUTCOMES SELECTED (SHORT & LONG)	
LEARNING	INCREASED STUDENT ATTENDANCE
	INCREASED ACHIEVEMENT (EQUITY)
	EQUITABLE DISTRIBUTION OF GREEN SCHOOLYARDS
HEALTH & WELLNESS	IMPROVED PHYSICAL HEALTH STUDENT
	INCREASE IN MOOD & MOOD STABILITY
	INCREASED NUTRITION
	REDUCTION IN LONG-TERM HEALTHCARE COSTS
	IMPROVED PHYSICAL HEALTH COMMUNITY
ENVIRONMENTAL	URBAN HEAT ISLAND REDUCTION
	REDUCED CO2 EMISSIONS
	POSITIVE EFFECTS OF TREE CANOPY ON AIR QUALITY
COMMUNITY	INCREASED STEWARDSHIP OF SCHOOLYARD
	DECREASED ABANDONED BUILDINGS/VACANT PROPERTIES
	INCREASED PROPERTY VALUE
	INCREASED SENSE OF COMMUNITY

3.2 Outcomes Selection Process

The project team worked with DPS staff to collect data spreading across 17 different departments/offices. We recognize their efforts and appreciate their assistance throughout the study. The diagram to the right illustrates the breadth of departments contacted during the data gathering phase. Green denotes engagement and some level of data retrieval. Yellow denotes engagement with minor data retrieval and white denotes engaged but no data available. Obstacles to data retrieval included district's staffing capacity to retrieve data, absence of reporting or change in reporting methods and granularity of data requested.

Denver Public Schools Department Organization Chart

Data collection covered a 15-year period and was sorted into "buckets" based on outcomes and the granularity of data at the school level. DPS, as with most school districts, has a process for coordinating research activities through a Research Review Board (RRB). Given the availability of DPS and CDE data at the school level and time constraints on the project, the lengthy RRB process for pupil level date was not inititated. The chart below illustrates the final selection for data retrieval. The data types in pink, were not included as they require pupil-level data.

Learning Landscapes Outcome Data Buckets & Types Selected

DATA BUCKETS	DATA TYPES
ACHIEVEMENT	ADVANCED PLACEMENT ENROLLMENT
	PERFORMANCE FRAMEWORK
	MATH & WRITING GROWTH
ENROLLMENT TRENDS	TRUANCY / CHRONIC ABSENTEEISM
	DROP OUT RATES
	GRADUATION / COMPLETION RATES
	STUDENT ENROLLMENT
	MOBILITY / STABILITY RATES
EQUITY	NEIGHBORHOOD POVERTY
	EQUITY INDEX
	ENVIRONMENTAL JUSTICE ZONES
	TITLE 1-A SCHOOLS
STUDENT HEALTH / WELLBEING	SCHOOL LUNCHES
	VEGETABLE GARDEN PRODUCTION
	STUDENT'S PHYSICAL HEALTH
	NUTRITION LEVELS

DATA BUCKETS	DATA TYPES
GREEN SPACE EFFECTS	TREE CANOPY COVERAGE
	SITE SURFACES
	TEMPERATURES
FACILITIES	MAINTENANCE COSTS
	ENERGY COSTS
	COMPOSTING
COMMUNITY USE	FAMILY AND STUDENT SATISFACTION
	OUTDOOR SCHOOL PERMITS
COMMUNITY VOLUNTEERING	COMMUNITY VOLUNTEERING
VANDALISM	VANDALISM COUNTS
GRAFFITI	GRAFFITI COUNTS
SAFETY & DISCIPLINE	Expulsion Rates

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Learning Landscapes is a valuable case study given its wealth of "impact over time" pre- and post-construction data spanning almost two decades. However, the study needed to account for changes in reporting and tracking programs that occurred during the study period and multiple construction phases where different groups of schools were constructed at different times.

Learning Landscapes Construction Timeline

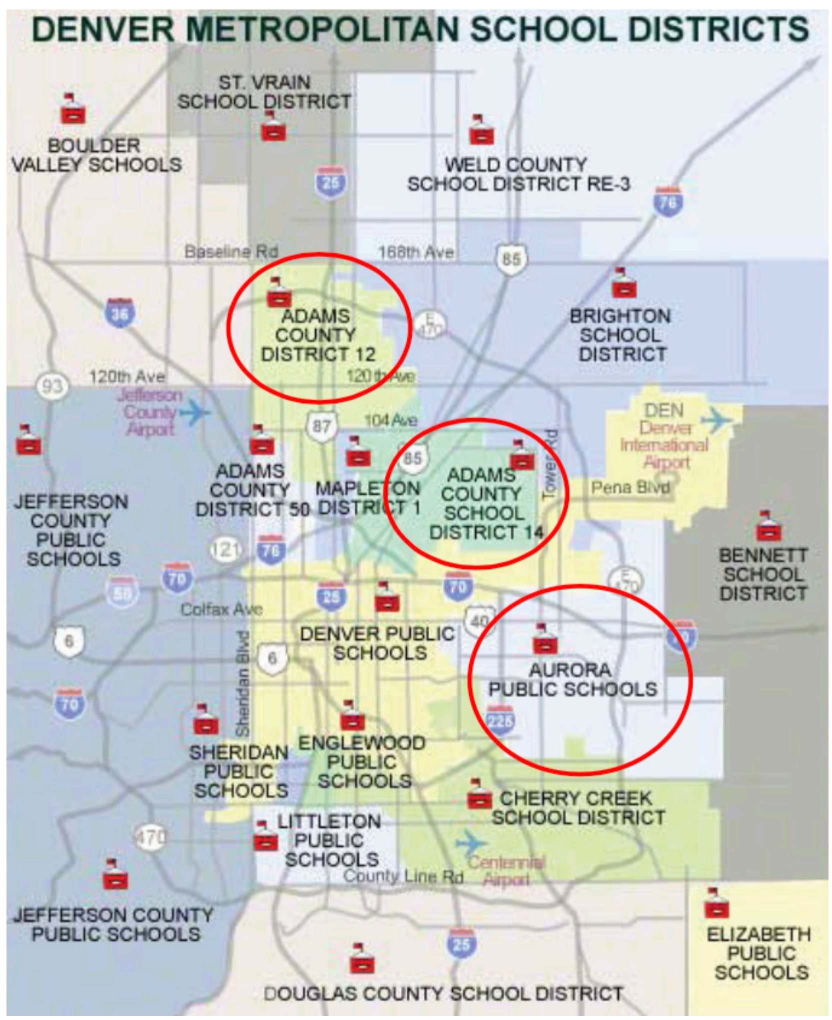
Treatment Group Number	Treatment Year	Number of Schools in Group	Used as a Treatment School	Used As a Not Yet Treated school
1	2000	3	Used 2004-2019	Never Used
2	2001	3	Used 2004-2019	Never Used
3	2002	9	Used 2004-2019	Never Used
4	2003	6	Used 2004-2019	Never Used
5	2004	10	Used 2004-2019	Never Used
6	2005	12	Used 2005-2024	Used 2004
7	2006	3	Used 2006-2019	Used 2004-2005
8	2007	2	Used 2007-2019	Used 2004-2006
9	2009	20	Used 2009-2019	Used 2004-2008
10	2010	14	Used 2010-2019	Used 2004-2009
11	2011	13	Used 2011-2019	Used 2004-2010
12	2012	4	Used 2012-2019	Used 2004-2011

The table above illustrates how some schools are both post- (treated) and pre- (non treated) construction schools given a particular year. In addition to pre- and post-construction Denver Public Schools, the analysis incorporated control schools (80) from neighboring districts, including Aurora Public Schools, Adams 12 and Adams 14 school districts.

Control Schools Chart

Neighboring Districts	Number of Schools
Aurora	44
Adams 12	29
Adams 14	7

These districts served as control/ pre-constution schools for the 2012 Intervention of Physical Activity in Youth (IPLAY) study, which investigated the impact of environmental (playground renovations) and curriculum interventions for elementary school children during the recess period.



4. Results

4.1 Research Questions

1. What quantifiable economic outcomes related to LL's are statistically significant?

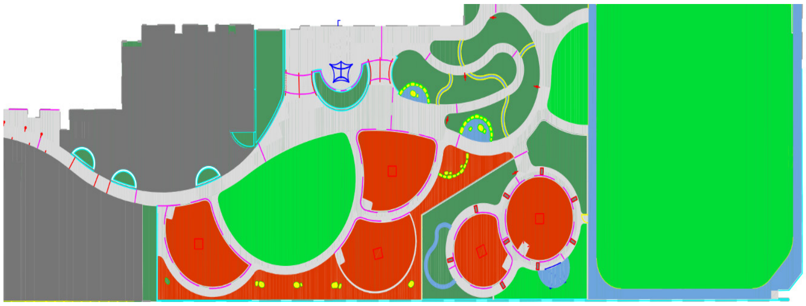
Since most research to date aggregates data to a school or class level, the impacts-over-time at multiple schools approach adds a new level of granularity to current research. This group-time average method looks at outcomes over time from 2004 to 2019, stopping prior to the COVID pandemic. Regression-based statistical modeling using Colorado Department of Education data revealed statistically significant Learning Landscape benefits with a confidence beyond 95% for seven student outcomes.

The CDE did not start collecting math and writing scores until 2012 and school performance until 2010 which presents limitations on pretreatment data. Hence, another model approach was used incorporating matching demographics and post-2021 data. When observing these results, they suggest a statistically significant increase in annual math mean growth of 8.5 percentage points, an increase in annual writing mean growth of 5.4 percentage points annually and an increase in an annual school performance framework of .12 percentage points.

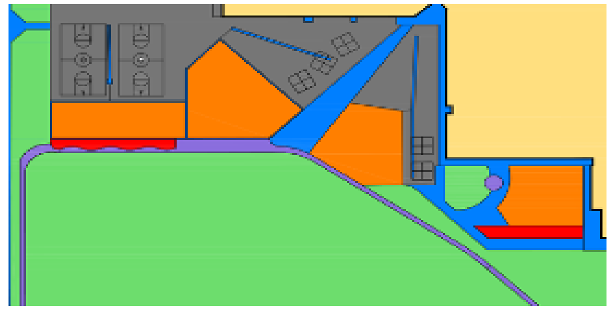
Statistically Significant Learning Landscape Outcomes Annually

Student Outcomes	Coefficient	Data Availability
Math Growth Increase	8.5%pt.	2012-2019
Mobility Reduction	7%pt.	2007-2019
Writing Growth Increase	5.4%pt.	2012-2019
Student Enrollment Increase	152/yr	2004-2019
Free & Reduced Lunches reduction	.17%pt.	2005-2019
School Performance Framework Increase	.12%pt.	2010-2019
Truancy Reduction	.009%pt.	2005-2019

What additional impacts from the presence of Learning Landscape schoolyards can be gleaned? The pre(2012) and post(2018) site surfaces data captured can determine if some LL's elements have stronger associations than others with learning outcomes. To achieve this objective, a "snapshot" or cross-sectional statistical regression model at one point in time(2018) is used. DPS Facility Management shared their Grounds Work Book, an extensive data base of maintenance expenses and levels of service the grounds department achieves given its current funding and staff. The Grounds Work Book includes 22 site characteristics. Based on previous LL research, seven additional characteristics deemed valuable were included in the analysis. One of these entries, the number of CAD space entries, was included as a design indicator or density of the Learning Landscape elements. An example of two LLs with low and high space entries is provided on the following page.



Example of High Density Design Elements
Beach Court schoolyard site surface categories



Example of Low Density Design Elements
Castro Schoolyard Site surface categories

While the majority of outcomes proved insignificant, student enrollment's statistical significance is reflected in 9 schoolyard characteristics with density of the design (number of space entries) and swings being most significant. Green schoolyards are a visual asset in a community and serve as an attraction to increase enrollment at LL schools. This is further corroborated in the previous statistical analysis and is supported in the financial valuation section of this chapter.

Student Enrollment Statistically Significant Indicators

Schoolyard Characteristics/Indicators	Coefficient
Number of CAD space entries	9.5%
Presence of Swings	9.3%
Sports/All Purpose Fields	1.4%
Small Grass Play	3%
Total Irrigated Turf W/O Fields	2.5%
Edging (LF)	3.2%
Trimming (LF)	.009%
Asphalt Parking Lot & Driveway	3.7%
Total Asphalt	3.1%

Among schools with vegetable gardens or farms, the annual school performance framework increased by a statistically significant 8.25 percentage points. By 2019, 55% of Learning Landscapes had school and/or community gardens. Of those only ten schools had vegetable gardens prior to the Learning Landscapes program. Curretnly, 13 Learning Landscapes schools have garden-to-cafeteria programs.

The presence of vegetable gardens and the shift regarding student nutrition will be discussed further in the next section.

Students at Steele Elementary School and their summer harvest. 2012 credit Andy Knowak

2. What are the long-term implications of schoolyard greening interventions?

Learning Outcomes - As mentioned previously, this study is the first of its kind to explore 1) the impact of schoolyard greening over an extended period of time, and 2) a greening project district-wide. Browning and Rigolon (2019) examined 13 peer-reviewed articles to understand associations between academic outcomes, types of green spaces, and distances at which the green spaces were measured around schools. Greenness, and tree cover at the school and within 200 meters were associated with some increased academic performance especially in math and reading test scores. The results of this study corroborate previous research. Student outcomes in math and writing growth and student performance framework showed consistently better annual performance over a seven-year period.

Nutritional Health - Interviews with the District's Food and Nutritional Services (FNS) and the Office of Sustainability(OS) corroborate the long term positive impact of LL infrastructure improvements over the past twelve years that includes expanding vegetable gardens to over 50% of elementary schools, implementing a garden to cafeteria program and launching a district farm program. The gardens are sustained with support from NGO's, parents, teachers and community residents. Recently, OS acquired a garden coordinator and in FY22 12,250 lbs of garden-grown produce was donated from these gardens.

Garden Place Academy vegetable garden and orchard. 2018 photo credit Lois Brink

The Garden to Cafeteria Program makes a connection between the fresh produce that the students grow in the school garden to the salad bars in the cafeteria at lunch. In 2012, every DPS school received a salad bar. Using food safety protocols developed with the local health department, students and garden leaders harvest fruits and vegetables weekly from the school gardens, learn how to wash the large chunks of dirt off, weigh and record the amount of produce and then present the harvest to the cafeteria staff. This not only improves the health of the students, but it also generates revenue from lunch sales. The number of participating schools dropped during COVID, but FNS is looking forward to bringing on more schools. The chart below shows the annual total revenues in 2022 dollars, along with the number of schools participating each year. The gardens are co managed with FNS and OS.

Garden to Cafeteria Program Revenue

Year	# of Schools	Total Revenue	Revenue/School
2011	13	$2,010	$155
2012	15	$1,574	$105
2013	13	$1,323	$102
2014	17	$1,693	$100
2015	13	$1,918	$148
2016	13	$1,480	$114
2017	17	$2,304	$136
2018	12	$1,499	$125
2019	7	$2,250	$321
Total	**120**	**$16,051**	**$1,304**

Total Revenues	$16,051
Revenue Per School	$1,304

The district managed school-farm program began as part of the Learning Landscapes in 2012 with research provided from a grant with the Colorado Health Foundation. The study suggested that DPS could potentially grow 340,000 lbs of seasonally fresh produce on 21 acres of DPS land with a potential cost savings to FNS of $150,000 per year. This could account for 40% of the fresh produce DPS purchases annually. By farming on schoolyards, children and the community are exposed to locally grown food produce.

District Managed Farm Revenue Timeline

Year	Total Revenues	Bradley School Revenues	McGlone School Revenues	Schmitt School Revenues
2012-2013	$57,064	$21,019	$36,045	
2013 - 2014	$78,339	$37,241	not farmed due to construction	$41,098
2014 - 2015	$92,286	$39,022	$30,196	$23,068
2015 - 2016	$92,115	$39,803	$27,891	$24,421
2016 - 2017	$79,111	$25,620	$22,610	$30,882
2017 - 2018		not farmed water issues	not farmed school expansion	farmed by DPS
Total	**$398,915**	**$162,704**	**$116,742**	**$119,468**

In 2017, three Learning Landscapes were part of the school farm program with an annual revenue of $80,000. While two of the school sites have been dropped due to site constraints, the program is sustaining itself with the remaining site, Schmitt Elementary. This school continues to be farmed by DPS and a massive 1/2 acre district greenhouse was completed in the spring of 2022 allowing FNS to expand the growing season through out the academic calendar.

Environmental Health - Investing in a cool or green vegetative surface reduces the severity of extreme heat events by controlling the level of heat absorbed, radiated, conducted, and emitted into the surrounding area, i.e. affecting the ambient temperature. Cooling effects from better choices in vegetative cover and lighter surfaces can work towards sufficiently reducing heat stress-related fatalities, strokes and illnesses during extreme heat wave events, thereby a benefit to the community. Trees also provide a cooling effect due to the shade and respite provided by the increased canopy coverage. This is especially beneficial for play areas when children spend time outdoors during the day and can have important long term health impacts.

DPS Head of Food and Nutritional Services Theresa Hefner at the new greenhouse. Feb 23'. Photo Credit Lois Brink

The effects of green space on ambient temperature as the land cover changes before and after Learning Landscapes can be used to estimate the change in ambient temperatures in the surrounding area (Parshall et al., 2011; Sailor & Hagos, 2011, Ibsen et al., 2022). In addition to temperature, other environmental impacts covered as a part of the site surface analysis included the level of carbon sequestration, storage capacity, and the change in air contaminants deposited on vegetative surfaces (iTree Landscape, 2022).

A sample set of 19 school sites in the southwest planning region were mapped pre and post. This accounts for almost 20% of the LL schools in the district. This region was selected for its range of equity index levels as well as its relatively stable population since 2012. With the interest of understanding district level impacts, analysis of the southwest schools are used to provide a scaled up analysis to infer impacts to the district as a whole. Changes in ambient temperature in the surrounding area are estimated based on changes in land cover before and after Learning Landscape construction. On average, a 15 degree Fahrenheit reduction was observed during the peak of summer season (estimated to be between the middle of May to August every year). In addition to temperature, site surface analysis estimated the level of carbon sequestration, storage capacity, and the change in air contaminants deposited on vegetative surfaces. In Carbon sequestration and air pollution reduction values were analyzed over a 40-year period. When adjusted for an annual rate, 1,284 tons of carbon are sequestered annually across all converted schoolyards and 404 lbs of air pollutants are removed annually across all converted schoolyards.

3. What quantitative/deterministic analysis can be conducted from the additional data gathered during this project?

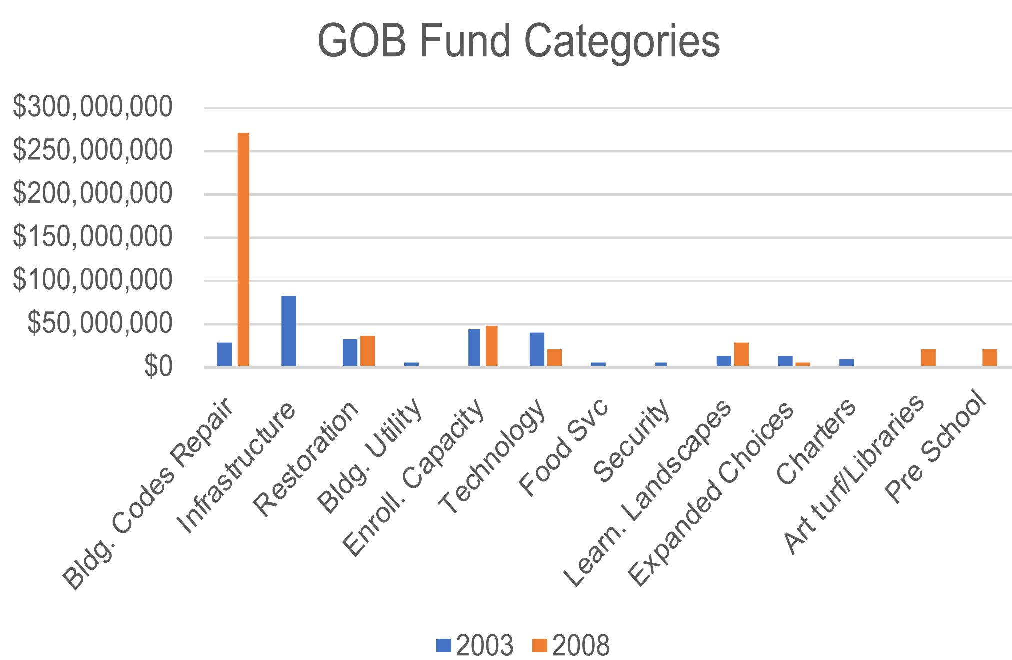
District Economics - The longitudinal analysis regarding student enrollment and revenue generated was calculated by taking the product of the inflation-adjusted per student funding that schools receive from the state based on their total enrollment. The Colorado Department of Education accounts for this increase by assuming a per student funding amount and appropriating the funds accordingly on the basis of total student enrollment. By retrieving the average annual increase in student enrollment of 152 the district has realized $1,341,777 of real income annually. The long term income realized from 2004 — 2019 is $20,126,655. This further substantiates the correlation between student enrollment and schoolyard greening/ redevelopment. The importance of the outward appearance of schools builds confidence in communities. We suspect this enrollment revenue will continue.

Ever since the successful completion of the initial Learning Landscape public/private funding campaign in 2003, the district has realized long term funding for schoolyard greening through General Obligation Bonds(GOB). The GOB funding process establishes a citizen advisory board who, during the course of 6 months, ranks and makes recommendations to the school board. Prior to the 2003 GOB, DPS had only one voter-approved bond. Of the $310,000,000 in the 2003 bond, 3.43% of the funding went to LL's. Over half of the funding went toward deferred building maintenance. In reviewing the fund categories, LL is the most forward facing/highly visible capital improvement project in the bond and covers all planning regions. The report from the board of education minutes is no longer available on line nor was DPS able to recover this information during the course of this project. Anecdotally, we have been told LL ranked high and was instrumental in voter confidence. In essence, for every dollar spent on LL's, $25 were realized in differed maintenance and several new charters. The same holds true for the 2008 bond where LL funding accounted for only 6% of the funding and deferred maintenance accounted for 70%.

Learning Landscapes Capital Costs

Learning Landscapes Periods	Capital Costs (2022 Dollars)
2000-2003	$8,920,724
2004-2008	$14,741,828
2009-2012	$36,818,629

Total Capital Costs	$60,481,181
Cost Per School	$630,012
Cost Per \SQFT	$2.23



In summary, when schoolyards are a community asset, GOB's are a powerful financial tool for districts to address deferred maintenance and access significant funding to scale schoolyard greening. Both issues plague many urban school districts.

4.2 Limits of Study & Next Steps

The results of this study offer substantial justification for investing in schoolyard greening. Most importantly it demonstrates that a greening program that is scaled across all elementary schools in a district creates a catalytic effect with quantifiable and statistically significant results in student outcomes and a district's financial health.

The DPS Research Review Board (RRB), which reviews research requests from external researchers, determined that CDE and DPS school-level data were sufficient for the analysis. The data types in pink require RRB approval in order to access pupil-level data..

Data Availability by Type

DATA BUCKETS	DATA TYPES
ACHIEVEMENT	ADVANCED PLACEMENT ENROLLMENT
	PERFORMANCE FRAMEWORK
	MATH & WRITING GROWTH
ENROLLMENT TRENDS	TRUANCY / CHRONIC ABSENTEEISM
	DROP OUT RATES
	GRADUATION / COMPLETION RATES
	STUDENT ENROLLMENT
	MOBILITY / STABILITY RATES
EQUITY	NEIGHBORHOOD POVERTY
	EQUITY INDEX
	ENVIRONMENTAL JUSTICE ZONES
	TITLE 1-A SCHOOLS
STUDENT HEALTH / WELLBEING	SCHOOL LUNCHES
	VEGETABLE GARDEN PRODUCTION
	STUDENT'S PHYSICAL HEALTH
	NUTRITION LEVELS

DATA BUCKETS	DATA TYPES
GREEN SPACE EFFECTS	TREE CANOPY COVERAGE
	SITE SURFACES
	TEMPERATURES
FACILITIES	MAINTENANCE COSTS
	ENERGY COSTS
	COMPOSTING
COMMUNITY USE	FAMILY AND STUDENT SATISFACTION
	OUTDOOR SCHOOL PERMITS
COMMUNITY VOLUNTEERING	COMMUNITY VOLUNTEERING
VANDALISM	VANDALISM COUNTS
GRAFFITI	GRAFFITI COUNTS
SAFETY & DISCIPLINE	Expulsion Rates

Legend

Grey - no data

Pink - pupil level data requires human subjects protocol

Green - Data captured at varying levels

Furthermore, due to DPS limited staffing capacity, accessing pupil-level data and information related to community use was not feasible. Other limitations include shifts in data storage, data conversion to new programs, and conflicting naming protocols.

The completion of this research and analysis opens opportunities to monetize impacts found to be significant at a granular level. Using the 12 LL treatment schools with the 12 control schools used in the 2012 research from adjacent districts we can investigate pupil-level variables and the effects on physical and emotional student health outcomes such as physical activity, nutritional offerings, and behavioral differences as well as graduation rates.

A priority for future research is securing funding for DPS to dedicate a staff person to the research project in order to access pupil-level and community use data. The district has in storage 20 years of satisfaction surveys by students and parents for each school. Given that community use is one of the biggest data gaps, this information would be invaluable to retrieve. Conducting audits at a cohort of LL sites would glean granular data regarding community and school use. Next steps would include exploring further monetization of variables with demonstrated differences between experimental and control groups and developing a pupil-level analysis framework that facilitates additional cost-benefit analysis.

Endnotes

1 https://www.childrenandnature.org/schools/greening-schoolyards/

List of References are located in the Appendix A.

Appendix A
Learning Landscapes Tech Memo

Autocase
Economic Advisory

learning landscapes
building community through play

BIG SANDBOX
building healthy neighborhoods

Table of Contents

1. Introduction

1.1 Background/Overview

This paper outlines the technical details of an economic and statistical analysis to support garnering insights into the impacts and outcomes of the Learning Landscapes (LL) program - an innovative and transformational schoolyard greening program within Denver Public Schools (DPS), aimed at supporting children's outcomes across multiple dimensions, the DPS district at large, as well as surrounding communities. In collaboration with The Big SandBox and University of Colorado Denver, Autocase Economic Advisory (a boutique economics advisory firm and economic software developer), conducted several quantitative analyses to analyze LL with a lens on impacts of the schoolyard that have both short-term and long-term economic benefits.

The LL program, completed in 2012, is a district-wide schoolyard greening project in the DPS system. The LL program consists of 99 kindergarten to 8th grade (K-8) schoolyards within DPS with a total area of 622 acres and capital costs of $43 million (2018 dollars).

Schoolyard greening offers academic, developmental, and social benefits that are typically discussed qualitatively but are widely recognized. When financially strapped urban districts must make tough decisions in the context of tight budgets, greening a schoolyard is not often seen as a cost-effective solution. New leverage points are needed to expose the value of enhanced schoolyards that create challenging educational and healthy environments and allow students to achieve their highest potential as learners and citizens. This project aims to conduct both inter and intra-district economic analysis of a district-wide schoolyard greening strategy in Denver supplemented with economic analysis of domains drawn from a comprehensive global literature review on similar programs and outcomes. The analysis efforts leverage empirical data to support evaluations with the goal to generate quantitative insights on outcomes to increase the development of green schoolyard projects across the country.

This project was dynamic in the fact that data drove the research and analytical roadmap – research interests were adjusted to meet this data availability. Ultimately, the research questions the analysis efforts were able to answer included:

1. What quantifiable economic outcomes related from LL's are statistically significant?
2. What are the long-term implications of schoolyard greening interventions on student outcomes and well-being at a static point of time and over time, as well as considering climate related issues?

With these questions in mind, the analysis efforts followed two phases and topics of the evaluation – a longitudinal time series analysis and a cross-sectional analysis.

- Phase 1 - Longitudinal analysis: compares DPS LL-treated schools with non-treated schools of neighboring districts (Aurora, Adams 12, and Adams 14 school districts) to determine if there are statistically significant effects on student outcomes as a result of LLs implementation using data from 2004-2019.

- Phase 2 - Cross-sectional analysis: compares differing LL's site surface profiles (size/scope design characteristics) within all DPS treated schools to determine if there are statistically significant effects on student outcomes from LL design characteristics using data from 2018.

Statistics is the study and manipulation of data, including ways to gather, review, analyze, and draw conclusions from data. In statistical analysis, regression is used to identify the associations between variables occurring in some data. It can show both the magnitude of such an association and also determine its statistical significance (i.e., whether or not the association is likely due to chance). Regression analysis is a powerful tool for uncovering the associations between variables observed in data. The goal in this case was to use statistics and regression analysis specifically to unearth if LL's effect on students or other outcomes.

An additional, separate analytical effort outside of the regression analyses focused on two key areas:

1) Financial Valuation:
    i) Depicting the costs of the LL program broken down within the DPS bond programs and funding periods.
    ii) Enumerating the revenues from LL-sourced produce sold at participating DPS lunch programs.
    iii) Additional funding from pupil revenue from the Colorado Department of Education and related state sources to DPS.
2) Site Surface Coverage Environmental Impacts Analysis:
    i) Geographic Information System (GIS) spatial data on the pre-LL surface profiles was compared with their post transformation surface coverage profile, i.e. converting area of concrete/asphalt impervious surfaces to vegetation and other materials that cool the surrounding area and absorb air emissions. This pre/post comparison depicts two key quantitative outcomes: the change in (1) urban heat island effect (UHI) and (2) carbon sequestration.

Data used in this project was collected from a wide variety of sources. For the regression analyses used to determine outcomes that were significant, data collection primarily centered on publicly available data from DPS as well as the Colorado Department of Education (CDE). The project team worked with a variety of DPS staff to collect data and recognize their efforts and appreciate their assistance throughout the study. As green schoolyards have multiple outcomes that require a wide range of data buckets to enable a comprehensive analysis, the data collection process was an effort in engagement:

- 17 different departments/offices within in DPS
- Colorado Department of Education

Data requested and sourced included the following categories: achievement; enrollment trends; green space effects; facilities; community use; schoolyard surfaces; and student health and wellbeing, among others.

The ancillary evaluation efforts included more data from DPS departments, as well as GIS data pulled and assessed in collaboration with the Department of Geography & Environmental Sciences at the University of Colorado Denver.

The starting point of this study involved conducting a detailed global literature review, focused on identifying peer-reviewed studies related to the topic of greening schoolyards and outcomes. These outcomes then formed the basis for the longitudinal statistical analysis.

This document outlines the literature review, the longitudinal and cross-sectional regression analyses, as well as the the financial and surface coverage environmental impacts quantification - including methodologies, data, and results.

1.3 Literature Review

Green spaces and access to nature have numerous benefits for society. By greening schoolyards, communities would be able to provide safe, accessible, natural areas, a larger educational space, and thereby create resources that benefit the school and the surrounding community. LL's schoolyard designs actively engage the school community throughout the planning, design, construction, and maintenance of the yard. As a part of this project, every elementary Denver Public Schoolyard has been transformed into a vibrant and healthy play space. These investments are expected to show beneficial student outcomes in terms of improved test scores and other tangible child outcomes. Additionally, green areas provide benefits in terms of improved health and wellness, learning, and a myriad of other benefits.

A literature review was conducted with the aim of supporting an econometric/statistical analysis of the outcomes of LL's. A preliminary list of outcomes was determined from the Children & Nature Network's list of benefits obtained from greening schoolyards. The list of final reviewed outcomes were narrowed down by reviewing the possibility of quantification and ease of fit into econometric modeling. The Web of Science, Children & Nature Network Research Library, and Google Scholar were all used to conduct searches for literature using key terms related to the targeted outcomes of LL's. A list of 33 papers of interest were chosen for inclusion as examples of applicable literature. The papers reviewed were selected according to the presence of quantitative and statistical analyses, in order to find gaps that could be filled with the subsequent econometric analysis. The absence of coverage of certain outcomes in this literature review does not reflect an absence of qualitative literature, nor does it suggest it will not be the subject of further review. Absence of coverage suggests the team did not find quantitative analyses of high quality that supported certain outcomes.

The distinctive schoolyard design elements in LL projects consist of:

- Community gateways and gathering spaces

- Public artworks
- Age-appropriate play equipment
- Grass playing fields
- Colored structured and unstructured asphalt games
- Custom shade structures
- Vegetable gardens
- Habitat areas/nature play

The broad list of effects garnered from literature can be broadly categorized under four key areas: Learning, Health & Wellness, Environmental, and Community Outcomes. These are synthesized below:

- Learning Outcomes
  - **Increased student attendance & principal referrals:** schoolyard improvements may be expected to lead to decreased student absenteeism and principal referrals (Brookmeyer, Fanti, and Henrich, 2006; Shochet et al., 2006; Ingul et al., 2011)
  - **Dropout rates:** It is suspected that schoolyard improvements will lower dropout rates in high school settings and have trickle down effects on future employment and income prospects, although not been broadly covered by the literature. Poor student mental health is considered a risk factor for students dropping out of school (Dupere et al., 2018; Hjorth et al., 2016; Freudenberg., 2007)
  - **Enrollment rates:** Schoolyard improvements will help to retain students in public schools as they transition from elementary to middle school, and between grades, or increase enrollment as parents that previously have favored homeschooling or private schools may now favor schools in the district. Thus far, the literature does not contain a link indicating there is a positive effect (Bruns et al., 2004).
  - **Improved academic achievement:** Schoolyard improvements may have a positive effect on student average test scores, brought about by increased time spent playing, a higher sense of emotional well-being at school, or other factors (Kuo, Browning, and Penner, 2018; Otte et al., 2019; Browning and Rigolon, 2019; Kweon et al., 2016).
  - **Long term unemployment:** Eide and Showalter (2008) found there was a relationship between school quality and unemployment in the decade post-graduation. However, this relationship did not last after the initial decade. Additional studies have also shown correlation, however, quantification of such effects requires a student by student data collection process and follow up through their journey in school, college and workforce (Riddell and Song, 2011).
- Health & Wellness Outcomes
  - **Increased play and physical health:** Anthamatten et al. (2014) conducted a spatial analysis to determine the relationship between the density of playground features and moderate to vigorous physical activity. OLS methods were used to analyze data collected using SOPLAY best practices, for observing the physical activity. Children were observed at different levels of physical activity, recreating

in different zones of the play area characterized by different features. They found that children increased physical activity in zones where there was more feature density, and a reduction in sedentary play (Brink et al, 2010; Engelen et al., 2013; Bundy et al., 2017)

- Environmental Outcomes
    - **Student mental health - improved mood:** Improving schoolyard conditions, and adding green space and natural elements, is hypothesized to improve different aspects of childhood mental health and social interactions (Bohnert, and Gerstein, 2018; Amoly, et al, 2014).
    - **School lunch sales:** Studies have shown a low consumption of fruits and vegetables at school – an average consumption of 0.10 +/ 0.1 cup-equivalents of vegetables per day at a school lunch per student (Cotunga et al., 2012). A study by Cotunga et al. (2012) showed an increase of 11-39% in students purchasing/selecting salads for their lunch at school as compared to the control group.
    - **Nutrition:** The availability of fresh produce (grown in the schoolyards) as a part of school lunches may contribute to a higher caloric intake per student. The literature reviewed thus far has been inconclusive on the caloric benefits - but has been more focused on self-reported questionnaires or tests on students' willingness to eat more vegetables and recognition of vegetables as a healthy source of food in younger children (Hart et al, 2010; Davis et al, 202; Lineberger & Zajicek, 2000; Khan & Bell, 2019; Morgan et al., 2010; Leuven et al., 2018).
- Environmental Outcomes
    - **Composting programs:** Increased availability in green spaces and outdoor learning is expected to increase volunteer or student activities such as composting. This impact is heavily dependent on the availability of program specific data to measure the effect size.
    - **Urban heat island and temperature impacts:** An increase in vegetative surfaces and tree canopy coverage is expected to provide a cooling ambient effect that has been shown to provide a multitude of benefits to the community including the reduction of the urban heat island effect.
    - **Carbon sequestration:** A vegetated cover provides the benefit of carbon sequestration. This occurs through the accumulation of carbon in above and below-ground plant biomass as well as in the soil beneath the vegetation as soil organic carbon.
- Community Outcomes: *Community outcomes represented the largest gap in the literature, including very little in the way of quantitative or statistical analysis. This is likely due to the nebulous nature of measuring community cohesion, and family engagement. There are two impact indicators that were attempted to be assessed using data collection, but sufficient information was not available per school to run a detailed analysis.*
    - **Vandalism**
    - **Graffiti reductions**

While data points have not been retrieved to evaluate every single impact listed above, the literature provides evidence for detailed future data collection to expand the current analysis. The impacts covered by the study include student outcomes such as:

- Truancy
- Mobility
- Pupil membership
- School Performance
- Math and writing growth
- Free and reduced lunch;
- Green space effects on ambient temperature and carbon sequestration.

Truancy is considered an inexcusable absence. It indicates that a student is absent from school without a valid or verifiable excuse by their parents or guardians. Student mobility measures the amount of times a student leaves a school or district, not accounting for departures that result from graduation. Pupil membership represents the count of student enrolment in a school as of the month of october. School performance represents a school percentage rating on various indicators such as English, math, and science performance, graduation rates, dropout rates and participation rates. Math and Writing growth are the median growth percentile which is a ranking from 1 to 99 which measures the students academic progress comparative to their peers. Free and reduced Lunch is a measure of the lunches provided to students that are either free or sold at a reduced price. Ambient temperature is the temperature of the air surrounding a component in this case the school yard. Carbon sequestration involves the process of capturing and storing carbon dioxide that would have been dispersed in the atmosphere.

This reduced list of impacts is a reflection of limited data captured, availability, and inconsistency in the data reporting mechanisms. Impacts have been assessed at a point of time as well as over a longer period of time, with detailed explanations on methodology specified in the next section.

2. Statistical Analysis

2.1 Overview

The statistical analysis of this report involves observing the effects of the LL redevelopments on child behavioral and educational outcomes. The analysis approaches this objective from two different perspectives or phases. Phase 1 is a longitudinal analysis and Phase 2 is a cross-sectional analysis.

The Phase 1 longitudinal analysis primarily compares outcomes between DPS-treated schools with non-treated schools of neighboring districts. The focus is to determine if there are effects on behavioral and educational outcomes as a result of LL implementation. The Phase 2 cross-sectional analysis compares outcomes within all DPS treated schools at one point in time. The objective is to assess effects on student outcomes based on site surface profiles between different LL's. The focus is on determining if size/scope of a LL can have an impact on outcomes. Where Phase 1 seeks to answer the question of whether implementing a LL is effective on producing good outcomes, Phase 2 seeks to answer the question of whether some LL's produce better outcomes compared to others based on site surface profile.

The next subsections will provide an overview of the Phase 1 longitudinal analysis followed by the Phase 2 cross-sectional analysis.

2.1.1 Phase 1: Longitudinal Analysis Overview

The Phase 1 analysis compares data across schools and throughout time; hence, the addition of a temporal element creates a longitudinal analysis. The analysis focuses on observing student outcomes across multiple schools over a time period of 16 years from 2004-2019. The analysis observes a set of treated schools that received the LL's treatment and a set of control schools that never received treatment. The treated schools were elementary schools from Denver Public Schools that received the treatment in different groups incrementally over a period from 2000-2012. By 2012, all DPS schools had experienced the LL's treatment. As the earliest available data source begins in 2004, schools that underwent treatment are observed from 2004-2012. The control schools were from the neighboring districts of Adams 12, Adams 14, and Aurora.

The original approach involved comparing outcomes within the same group of DPS Schools being treated. The outcomes associated with the schools while they already received treatment would be compared to the outcomes associated when they had yet to receive the treatment. The issue with this approach involves a bias that occurs when the outcomes from treated schools and not-yet-treated schools are observed in different time periods. This time bias occurs when there is an outcome such as truancy that trends positively with time. If truancy is increasing over time, then the lower values in the past will be more associated with the not yet treated schools in the past. The higher values of truancy will be more associated with the treated schools more in the future. Thus, this association falsely indicates that the treatment of LL's development causes higher values of truancy when this may not be the case. Therefore, treated and untreated schools need to be observed in the same time period to account for the time bias.

The introduction of control schools from neighboring districts that were never treated addresses this issue. It allows for comparisons between treated schools and untreated schools within the same time period, which allows one to control for this bias which exists when comparing observations from different time periods. There remain many other differences that can arise from having two different groups of schools from different districts, such as differences in socio-economic factors. However, the model addresses such differences, as explained in more detail in the methodology section.

It is important to note that this analysis was intended to extend to assessing the various effects that LL's would have on outcomes considering various socio-economic factors such as gender, race and equity. One approach was to dissect the schools according to five groups varying in stages of equity according to an equity index. Separate analyses would be conducted with a comparison amongst the results. However, once the data was segmented, the sample size of schools were insufficient for regression modeling. While modeling could not be conducted by equity or other socio-economic factors, the equity index was still utilized as a valuable control variable in the Phase 2 cross-sectional analysis, which will be discussed further in the next sub-section.

2.1.2 Phase 2: Cross-Sectional Analysis Overview

The Phase 2 analysis is a cross-sectional analysis as it only makes comparisons "across" all schools at one point in time. A longitudinal approach was not considered as including a time element would contribute no additional benefit as the site surface profiles do not change over time once already changed after LL's. However, there is variation when comparing site surface profiles across schools, which is why a cross-sectional analysis across schools is appropriate.

The analysis involves observing student behavioral and educational outcomes in relation to changes in site-surface amongst all LL schools during the year 2018. The objective is to determine if there are any significant impacts on student outcomes based on the size and scope of the LL. Changes in site surface profiles across schools such as area of irrigated turf, number of trees, area of fields etc. are observed and compared with changes in the student outcomes across these schools in order to determine any significance in improved student outcomes due to extensiveness of site surface profiles.

2.2 Data

This section will discuss in detail the data used to conduct the modeling of the Phase 1 and Phase 2 statistical analysis as well as the sources from which the data was retrieved.

2.2.1 Phase 1: Longitudinal Data

The data used in the longitudinal analysis can be grouped into three segments: (1) the DPS Treated Schools, (2) the Aura, Adams 12, and Adams 14 control schools, and (3) the outcome variables,

2.2.1.1 The DPS Treated Schools

There are a total of 99 DPS schools accounted for in this study. Table 1 shows the breakdown of the schools according to their treatment groups and their year of treatment. The treatment groups of schools are also defined by when they are used as treated schools in the model and when they are used as not-yet-treated schools to be associated with the control schools. As the study period covers 2004-2019, all schools that experienced treatment in 2004 and earlier are immediately considered treatment schools at the beginning of the study and cannot be used at any point as not-yet-treated schools. Regarding treatment groups that gradually experience treatment in 2005 and later, they are considered not-yet-treated and are associated with the control schools prior to their treatment year. Once they become treated, they are considered treatment schools for every subsequent year. Once the last group in 2012 has been treated, all DPS schools moving forward are considered treated schools with no schools associated as not-yet-treated schools. As there are no more not-yet-treated schools available for comparison in 2012 and after, the need for a group of control schools in the other districts that were never treated is present.

Table 1: Treatment Groups of DPS Treated Schools

Treatment Group Number	Treatment Year	Number of Schools in Group	Used as a Treatment School.	Used As a Not Yet Treated school
1	2000	3	Used 2005-2019	Never Used
2	2001	3	Used 2005-2019	Never Used
3	2002	9	Used 2005-2019	Never Used
4	2003	6	Used 2005-2019	Never Used
5	2004	10	Used 2005-2019	Never Used
6	2005	12	Used 2005-2019	Used 2004
7	2006	3	Used 2006-2019	Used 2004-2005
8	2007	2	Used 2007-2019	Used 2004-2006
9	2009	20	Used 2009-2019	Used 2004-2008
10	2010	14	Used 2010-2019	Used 2004-2009
11	2011	13	Used 2011-2019	Used 2004-2010
12	2012	4	Used 2012-2019	Used 2004-2011

2.2.1.2 The Aurora, Adams 12, and Adams 14 Control Schools

The control schools in this study from neighboring districts are 80 in total. The number of schools used from each district can be seen in Table 2 with the most schools used belonging to Aurora Public Schools.

Table 2: Number of Control Schools From Neighboring Districts

Neighboring Districts	Number of Schools
Aurora	44
Adams 12	29
Adams 14	7

2.2.1.3 The Outcome Variables

The type of student outcomes collected and their data availability for each outcome can be seen in Table 3. Five out of the nine outcomes cover roughly the entire study period. Two of the nine variables, mobility and school performance, cover a portion of the period before the treatment of all schools in 2012. Another two of the nine variables, math and writing growth, span only the portion of the period after all schools are treated in 2012. This raises some challenges as there is no data on these outcomes during the years when schools were not treated. Outcomes after treatment cannot be compared with outcomes prior to treatment, due to their absence. As a result, a different approach is used to model these two variables, which is further outlined in the methodology section.

Table 3: Data Availability on Student Outcomes

Student Outcomes	Data Availability
Truancy %	2005-2019
Mobility %	2007-2019
Math Growth (Mean growth %)	2012-2019
Writing Growth (Mean growth %)	2012-2019
School Performance Framework	2010-2019
Pupil Membership	2004-2019
Free and Reduced Lunch Membership %	2005-2019

The student outcome data of pupil membership, free lunch, reduced lunch, and free and reduced lunch were collected directly from DPS, while data on all other outcomes were collected from the Colorado Department of Education (CDE).

2.2.2 Phase 2: Cross-Sectional Data

The data used in the cross-sectional analysis consists of these variables for each DPS School: (1) the outcome variables, (2) the site surfaces/profiles, and (3) the equity index used as a control variable

2.2.2.1 The Outcome Variables

The outcome variables used in the cross-sectional analysis are the same variables used in the longitudinal analysis. However, as this is an analysis across schools given one period of time in 2018, only the outcomes for the year 2018 are included in the data set.

2.2.2.2 The Site Surfaces/Profiles

There are 29 site surface/profile variables that were included in the cross-sectional regression model. Table 4 displays the names of all included variables, along with their respective unit type.

Table 4: Site Surface/Profile Variables

Variable Name	Unit		Variable Name	Unit
GIS Space Entries	#		Student/Comm Garden/Orchard	SQFT
Swings	#		Landscape/Boulders	SQFT
Non-Irrigated Turf - Native / Low Grow	SQFT		Play Equipment Area	SQFT
Sports/All Purpose Fields	SQFT		Playgrounds	#

Total Irrigated Turf W/O Fields - Front Lawn	SQFT		Asphalt Parking Lot & Driveway	SQFT
Total Irrigated Turf W/O Fields - Small Grass Play	SQFT		Asphalt Blacktop & Hard Surface Play	SQFT
Total Irrigated Turf W/O Fields	SQFT		Total Asphalt	SQFT
Total Irrigated Turf	SQFT		Entrance and street Sidewalk	SQFT
Soft Surface	SQFT		Walking paths - crusher fines	SQFT
Hand Mowed Grass LF	SQFT		Concrete Curb, Walking Path, Sidewalk	SQFT
Edging LF	SQFT		Total Concrete, Colored, Brick, Stamped, Cobblestone	SQFT
Trimming LF	SQFT		Total Concrete Non Vehicular	SQFT
Sprinkler Zones	#		Total Concrete, Driveway, Slab	SQFT
Tree Canopy	SQFT		Total Concrete	SQFT
EWF	SQFT			

The data concerning these variables were also retrieved from DPS and modified by researchers at UC Denver.

2.2.2.3 The Equity Index

The equity index is another variable that was added to the regression to control for any differences in school outcomes that may result from socio-economic differences already present amongst the schools. Without controlling for socio-economic differences, it would be very difficult to determine if any difference between school outcomes was a result of their site surface/profile or their socio-economic status. The index incorporates a multitude of various socio-economic factors into one value. The index value measures the level of inequity - the lower the index value, the more equity exists amongst the school demographics. Conversely, the higher the index value, the more inequity exists amongst the school demographics.

2.3 Methodology

This section will discuss the methodology behind both phases of the statistical analysis: Phase 1 longitudinal analysis and Phase 2 cross-sectional analysis.

2.3.1 Phase 1: Longitudinal Methodology

Concerning the Phase 1 longitudinal analysis there are two methodological approaches used. This is due to the data limitations that exist for some outcomes of interest. For the majority of outcomes with adequate data the primary method is used, while for those outcomes with limitations, a secondary method is used with additional assumptions. The two methodological approaches are as follows:

1) Group-Time Average Treatment Effect

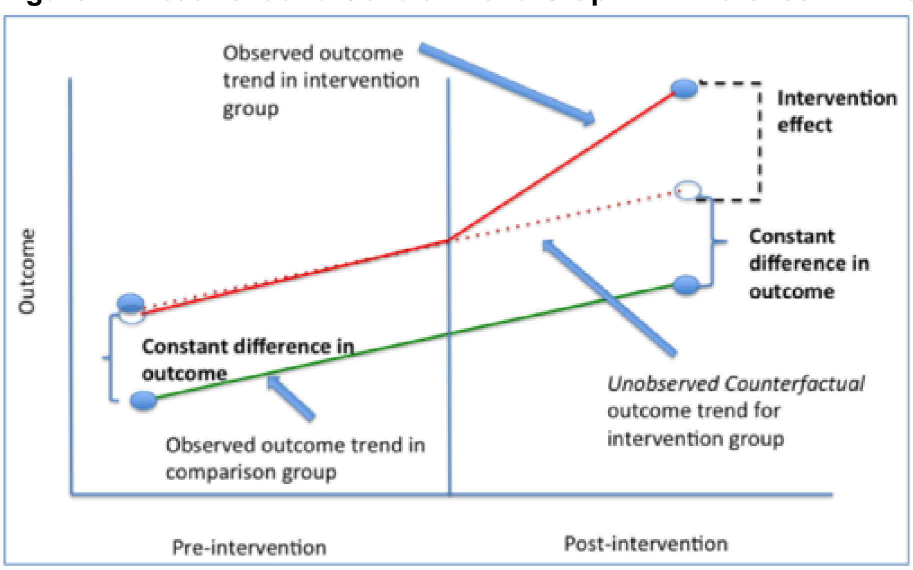
2) Post-2012 Comparison

It is important to note that the main method used and recommended in this study is the group time average effect. However, there is a simple variation of this method called the difference-in-differences (DID). Whereas the DID approach focuses on only one group of schools treated at one particular point in time, the group time average effect focuses on multiple groups being treated at different time periods. This notion relates specifically to the LL schools which experience the construction in different groups and at different times. The process of the DID approach is discussed in the following section to support the explanation of the primary method of this report, the group time average effect. The group time average effect is simply a generalized model of the DID approach as it allows for two or more groups. Thus, it can be stated that a group time average effect with two groups is the same approach as the DID approach.

2.3.1.1 DIfference in Differences/Group Time Average Effect of two Groups

The DID approach involves comparing the differences between a treatment group and a control group before and after the treatment year. It calculates the differences between the two groups before the treatment group is treated and also after the treatment group is treated and then takes the difference between those differences; hence, the name difference-in-differences. Simply calculating the differences between these two groups after treatment is not enough as these differences could have already been in existence prior to treatment. This is why the differences before and after treatment have another difference taken. This allows for any differences that existed prior to treatment to be removed, leaving only the additional difference which is the result of the treatment. This can be seen in Figure 1 below. The constant difference in outcome is what is removed, leaving the intervention effect remaining.

Figure 1: Treatment and Control Trend Graph in Difference in DIfferences Model



Source: https://www.publichealth.columbia.edu/research/population-health-methods/difference-difference-estimation

The data is divided into four main buckets, untreated prior to treatment, not-yet-treated prior to treatment, treated after treatment, and untreated after treatment. Given that there are only two periods, pre-treatment and post-treatment, the model calculation is simple. The first two buckets of data can be gathered with their differences taken in the first period, the last two data buckets can be gathered with their differences taken in the second period, and finally those differences in each period can have their differences taken.

The main limitation concerning this approach is that it only involves treatments occuring in one period with one treatment group. Whereas in the case of this Learning Landscape study, there are multiple groups of schools being treated at different times. This requires the need for a method that can incorporate the multiplicity of treatment groups and treatments that occur in various periods. The group time average treatment effect with more than two groups is such a method.

2.3.1.2 with more than two Groups

The group time average effect categorizes the data into the same four groups. However, the model calculation is more complex, moving from two time periods with one treatment to more than two periods with multiple treatments. Given this notion, the data buckets need to be defined appropriately before and after each treatment and calculated accordingly. The same data categorized to a particular bucket can change in categorization depending on which treatment period is in focus. For instance, suppose a set of schools is being treated in 2006. There will be all four data buckets of (1) untreated schools prior to 2006, (2) not-yet-treated schools prior to 2006, (3) treated schools after 2006 and (4) untreated schools after 2006. Now suppose the next set of schools to be treated are in 2008. The data in the first two buckets categorized as untreated and not-yet-treated schools prior to 2006 will also hold the same status prior to 2008. They can be used for the same buckets for 2008 (1) untreated schools prior to 2008 and (2) not-yet-treated schools prior to 2008. However, this is not the case for all the data in the third and fourth buckets of 2006. Any observations in the third bucket after 2006 but before 2008 would be considered treated already and can not be used as an untreated school or not-yet-treated school prior to 2008. Furthermore, any observations that are in the fourth bucket of 2006, (4) untreated after 2006 but before 2008, would shift buckets and would be considered untreated prior to 2008. This shift occurs as the treatment period of focus shifts from 2006 to 2008. Thus, as the treatment of focus shifts, some data cannot be used and other data shifts between buckets and is defined differently based on the treatment year of focus. Therefore to address these concerns, the group time average treatment method is employed to account for these variations.

A generalization of the two-period model to incorporate more than two periods was Introduced by Callaway and Sant'Anna (2021). Their notation outlining the model is as follows:

- $\mathbf{Y}_{it}\mathbf{(0)}$ is the untreated potential outcome, represented as "(0)", of school "*i* " at year "*t* ". This is the outcome that school "*i* " would experience had they not participated in the treatment.
- $\mathbf{Y}_{it}\mathbf{(g)}$ is the potential outcome of school "*i* " at year "*t* " if they are treated in period g, where g represents the period in which treatment occurs

- **G_i** is the time when school "*i* " is treated. As schools are treated, they are grouped according to different periods of treatment inline with the time of treatment.
- **C_i** is an indicator variable that indicates whether school "*i*" belongs to a never-treated group.
- **Y_{it}** is simply the observed outcome of school "*i* " at time "*t* ". When **Y_{it}** = **$Y_{it}(0)$** in all time periods, it means school "*i* " is in the never treated group **C_i**. Schools "*i* " in other groups have observed outcomes identified as such:

$$Y_{it} = 1\{G>t\}Y_{it}(0) + 1\{G_i \leq t\}Y_{it}(G_i)$$

This means that for the current observation **Yit,** if the year school "*i* " is treated, **G**, is greater than the current time period "*t* ", then the current observation **Yit** has not yet been treated and is considered an untreated outcome **Yit(0).** Conversely, if the year School "*i* " is treated is less than or equal to the current time period "*t* ", then the current observation **Yit** has been treated and is considered a treated outcome **Yit(Gi)** at treatment period **Gi.**

The treatment effect is indicated by:

$$ATT(g,t) = E[Y_t(g) - Y_t(0)|G = g]$$

This demonstrates that the ATT or treatment effect is the expected value of the difference of the treated outcomes for schools in group "**g**" and the untreated outcomes conditional upon the treatment of schools belonging to treatment group "**g**".

In this particular analysis the time period of assessment spans from 2004-2019 with seven groups where treatment occurs for every year from 2005-2012, with exception to 2008. Where **g** = 2 indicates the fist group being treated in time period two. Notice that **g** cannot equal one as in the first time period no groups are treated. Thus, ATT(g=2,t=9) is the average treatment effect of the group that experiences treatment in time period two, at time period nine. Furthermore, ATT(g=8,t=8) is the average treatment effect of the group that experiences treatment in time period eight, at time period eight.

Once the model is run for each outcome variable, the average treatment effects can be aggregated by treatment groups and presented into a results table.

The group average treatment effect is the primary model used in the Phase 1 longitudinal analysis. However, given certain data limitations with respect to a couple of the outcome variables, the approach outlined in the following section was also included in the analysis.

2.3.1.3 Post-2012 Effect Between DPS and Aurora, Adams 12 and 14 Public Schools

Both of the previous methods require each school's data before and after treatment in order to make a comparison. However, in the case of math and writing growth, data was only available from 2013-2019, which is after all LL's have already been in effect. There is essentially no pre-LL data for these two variables. While school performance had data pre-LL, that data was limited to only 2 years. Thus, the post-2012 comparison is used to model Math and writing scores with no data pre-treatment and as well for school performance with limited data pre-treatment.

The post-2012 analysis involves comparing the outcomes between the treated DPS LL's schools and the untreated control schools after 2012. This allows for a treatment/control comparison in the same time period. After 2012, all LL schools are considered treated and compared with the non-treated Aurora, Adams 12 and Adams 14 schools in the same time period. The regression models can be represented as such:

$\underline{Outcome_{it}} = \beta_{0it} + \underline{Treated_{it}} * \boldsymbol{\beta_{1it}} + \underline{Year}\beta_{2it} + \varepsilon_{it}$

Where,

- **i** represents a particular school
- **t** represents a particular year
- **Outcome**$_{it}$ is an outcome for a particular school(i) and year(t)
- **Treated**$_{it}$ is the treatment status of the schools (either one for a LL school in DPS or zero for an Aurora school). All DPS schools are considered treated as all projects were completed post-2012.
- **Year** is a year trend variable
- $\boldsymbol{\beta_{0it}}$ is the regression intercept
- $\boldsymbol{\beta_{1it}}$ is the estimated effect that treatment has on the outcome. (this is the main variable of interest). Thus, this is the ***average treatment effect***.
- $\boldsymbol{\beta_{2it}}$ is the estimated effect that years has on the outcome variable or the change in the outcome variable over time. This estimate is mainly included as a control to account for any changes in outcome data that are a result of time as opposed to the treatment
- $\boldsymbol{\varepsilon_{it}}$ is the error term

Note: Variables that are underlined represent the data to be inputted into the model, while variables that are not underlined represent parameters that are to be estimated

Once the regressions are run for both math and writing outcomes, the $\boldsymbol{\beta_{2it}}$ coefficients or average treatment effects can be reflected.

2.3.2 Phase 2: Cross-Sectional Methodology

Regarding the Phase 2 cross-sectional analysis, a statistical regression model is conducted comparing the effects of site surface profiles on learning outcomes amongst all LL's schools at one point in time. This allows one to determine if some LL's are more effective than others regarding their quality and extensiveness. The use of an equity index as a control variable is also employed in order to account for the differences in outcomes due to socio-economic factors. The site surfaces are observed in the year 2018, as all LL's were completed and it is the year in which the equity index was captured. Regressions were modeled for each sight surface and each outcome. The general regression model is as follows:

$\underline{Outcome_i} = \beta_{0i} + \underline{Equity\ Index_i}*\beta_{1i} + \underline{Site\ Surface_i}*\boldsymbol{\beta_{2i}} + \varepsilon_i$

Where,

- $\underline{Outcome_i}$ represents the learning outcome
- β_{0i} represents the intercept parameter
- $\underline{Equity\ Index_i}$ represents the equity index value for a given school
- β_{1i} represents the parameter estimate associated with the equity intercept
- $\underline{Site\ Surface_i}$ represents the value associated with a site surface measure (number of trees, number of shrubs, square footage of irrigated turf. etc.)
- $\boldsymbol{\beta_{2i}}$ represents the parameter associated with site surfaces, which is the main parameter of focus as it indicates the effect (if any) of the site surface on the outcome represented in the model
- ε_i represents the error term

Note: Variables that are underlined represent the data to be inputted into the model, while variables that are not underlined represent parameters to be estimated

Once all the models are run for all site surface outcomes, the $\boldsymbol{\beta_{2i}}$ coefficients or treatment effects can be presented in a results matrix for interpretation.

2.4 Results

This section will present results of the statistical analysis as segmented by the Phase 1 longitudinal analysis and the Phase 2 cross-sectional analysis.

Phase 1: Longitudinal Results

The group-time average method primarily used to model the longitudinal results provides the estimated effects for every treatment group of schools for every year. Reporting such results would be far too extensive and not as meaningful. To present them in a more meaningful way, the results are aggregated in two different forms. The first form involves taking an average of all statistically significant effects for each outcome. The second form involves aggregating the significant and insignificant results by each treatment year according to each outcome.

As discussed above, the data for the math and writing scores variables are only available from 2012 onward, after all schools were already treated. As a result any differences that already existed between treated and untreated control schools cannot be removed as the model needs to observe any difference prior to schools being treated. In this case, another method is used to predict the effects along with the results. These results will be reported with the first form of group-time average results, which averages all significant results from all years.

Table 5 displays the results coefficients which represent the effects of LL treatment on the respective outcome. Coefficients highlighted in green represent a statistically significant effect with a confidence beyond 95% that is consistent with improvement in the outcome. Coefficients in gray indicate that the coefficient is not statistically significant. This means that there is no effect beyond a confidence of 95%.

Table 5: Model Results For Comparison Between DPS LL Schools and Aurora, Adams 12 and Adams 14 Schools

Variable	Treated Coefficient*	Significance
Truancy %	-0.00935	Average of Statistically Significant Coefficients
Mobility %	-7.0434	Average of Statistically Significant Coefficients
Pupil Membership	152.407625	Average of Statistically Significant Coefficients
Free and Reduced Lunch Membership	-0.1711352941	Average of Statistically Significant Coefficients
School Performance Framework	0.0496375	Average of All Coefficients. No coefficients were Statistically Significant
The following Coefficients Are Modeled with a different Approach due to lack of data		
Math Growth**	8.4653	Statistically Significant Coefficient
Writing Growth**	5.4051	Statistically Significant Coefficient
School Performance Framework**	0.116667	Statistically Significant Coefficient

*Positive Coefficients reflect an estimate of annual increase in the variable and negatives reflect an annual decrease

** Math and Writing growth were estimated using another approach due to data only being available post 2012. Data was regressed post 2012 with cohorts of matching demographics between treatment and control groups

When interpreting the results in Table 5 using the group average treatment effect, the average effect of one year of LL implementation constitutes a reduction in truancy rate by 0.01%, a reduction in student mobility by 7%, an increase in pupil membership of approximately 152 students, a reduction in the use of free and reduced lunch by 0.17%, and no effect in school performance. It is important to note that regarding school performance, the data availability is limited from 2010-2019, leaving only two years of pre-treatment observation. It is possible that more years of pre-treatment observation may have resulted in a more statistically significant effect. As mentioned prior, data regarding Math and writing scores are more scarce with no pretreatment years available. Hence, another model approach was used incorporating matching demographics and post 2021 data for math and writing due to data absence. School performance is also modeled again with this method due to data limitations. When observing these results, they suggest an increase in math mean growth percentile by 8.5 points, an increase in writing mean growth percentile by 5.5 points.

Table 6 presents the results run by the same model, aggregated according to their treatment group. The green highlighted cells, like prior results tables, represent a coefficient which is statistically significant with 95% confidence. The effects on school performance remain statistically insignificant for all groups. While student mobility had a number of years that could be averaged in the prior results table, when aggregating all the results by treatment group, no treatment group showed statistical significance. The lack of significant results in school performance and mobility is likely due to the lack of available data as both variables contain the least amount of data amongst the outcomes listed. This is clearly evident as well in the lack of coefficients for these two variables in Table 6 relative to the other outcomes.

When observing all other variables, there seems to be a consistency of significant results across the treatment group of 2007. In 2007, the effect of LL's was a 0.007% decrease in truancy, an increase in pupil membership by 141 students, and a reduction in free and reduced lunch by 0.2%. Subsequent to 2007, free and reduced lunches decreased by 0.06% in the 2009 treatment group and 0.041% in the 2012 treatment group.

Table 6: Results Coefficient Aggregated by group

Treatment Group	Truancy %	Mobility %	School Performance Score	Pupil Membership	Free and Reduced Lunch %
2005				56.9069	
2006	0.005			39.3592	-0.0109
2007	-0.0071			141.4565	-0.2032
2009	-0.0055	-4.0259		42.7218	-0.0615
2010	-0.0021	-3.4367		-10.0703	-0.041
2011	0.0014	-2.2806	0.0306	7.5193	-0.0796
2012	0.0008	6.2373	0.0782	27.3152	-0.041

Phase 2: Cross-Sectional Results

The cross-sectional model involves a series of regression between each site surface and outcome. The effect coefficients from each regression can be seen in Table 7. Coefficients highlighted in green indicate statistically significant effects, with 95% confidence, indicating improvements in outcome. Coefficients highlighted in red represent significant effects that are declines in the outcome. Coefficients that are not highlighted are not statistically significant with 95% confidence.

When interpreting the coefficients, pupil membership experiences slight benefits from several site surface variables in comparison to the other student outcomes. Particularly site surfaces that can be observed more easily by the community, which would indicate such desire to enroll more students. Apart from pupil membership, the majority of coefficients are not statistically significant which indicates that there is not much difference in student outcomes as a result of the size and scope of the site surface profiles of LL's. This is both seen from the lack of statistical significance as well as the small effect size of the coefficients. These small effect sizes are also present with pupil membership, though being statistically significant.

When comparing these results with the longitudinal results, this indicates that there is more of an effect resulting from LL implementation than the size or scope of the LL being implemented.

Table 7: Results Coefficients of Site Surfaces

Outcomes/ Indicators	Truancy %	Mobility %	Pupil Membership	School Performance	Math Median Growth Percentile	Writing Median Growth Percentile	Free and Reduced Lunch %
Number of Space Entrees	-1.75E-05	-2.62E-04	9.46E-01	4.12E-04	3.40E-02	1.99E-02	-6.53E-04
Number of Swings	-7.02E-05	5.66E-04	9.35E+00	3.73E-03	2.71E-01	-3.15E-01	-1.62E-04
Non-Irrigated Turf - Native / Low Grow	6.66E-09	5.25E-07	1.68E-03	1.66E-06	2.19E-04	1.27E-04	-1.50E-06
Sports/All Purpose Fields	-8.26E-08	-2.27E-07	1.43E-03	-2.23E-08	-8.01E-07	-3.45E-05	-2.59E-07
Total Irrigated Turf W/O Fields - Front Lawn	-3.87E-08	-1.16E-07	3.39E-03	8.04E-07	6.68E-05	-1.66E-05	-1.49E-06
Total Irrigated Turf W/O Fields - Small Grass Play	-1.08E-07	-6.10E-07	2.97E-03	3.05E-07	7.54E-05	9.57E-06	-4.06E-07
Total Irrigated Turf W/O Fields	-8.02E-08	-2.04E-07	2.53E-03	1.87E-07	3.69E-05	-1.89E-05	-3.79E-07
Total Irrigated Turf	-4.92E-08	-1.44E-07	9.97E-04	-8.20E-09	1.02E-06	-1.54E-05	-3.97E-07
Soft Surface	9.92E-08	1.93E-07	9.97E-04	-1.22E-06	-9.78E-05	-7.97E-05	1.32E-06
Hand Mowed Grass LF	-1.76E-06	-7.50E-06	1.73E-02	5.60E-05	3.33E-03	3.07E-03	1.37E-04
Edging LF	-1.37E-06	-3.97E-06	2.85E-02	-3.18E-05	-2.08E-03	-2.82E-03	4.15E-06
Trimming LF	-1.30E-06	-3.53E-07	3.15E-02	-7.10E-06	-4.65E-04	-7.43E-04	-5.08E-06
Sprinkler Zones	-1.78E-04	-5.39E-04	9.62E-01	-4.42E-04	-1.76E-01	-6.76E-02	-2.52E-03
Tree Canopy	4.54E-07	2.85E-06	-8.37E-04	7.97E-07	-4.25E-04	1.92E-04	4.39E-07
EWF	-4.23E-07	-1.40E-06	2.29E-03	-1.02E-06	-3.00E-04	-2.59E-04	-2.50E-07
Student/Comm Garden/Orchard	-2.52E-07	-2.67E-10	-4.81E-03	8.25E-06	5.57E-04	1.53E-04	1.53E-05
Landscape/Boulders	-5.10E-08	7.46E-07	-1.45E-03	2.38E-06	1.15E-05	1.46E-04	-1.08E-08
Play Equipment Area	-5.06E-07	-2.30E-06	1.55E-03	-4.85E-06	-1.20E-04	-3.53E-04	6.66E-06
Playground Qty	9.73E-04	4.09E-03	3.09E+00	-1.24E-02	-1.69E+00	-1.70E+00	7.37E-03
Asphalt Parking Lot & Driveway	-2.11E-07	-7.59E-07	3.71E-03	-1.72E-07	3.15E-05	-4.63E-05	-1.76E-07
Asphalt Blacktop & Hard Surface Play	-8.85E-08	2.08E-07	3.15E-03	-1.04E-07	-1.35E-04	-1.33E-04	-7.78E-07
Total Asphalt	-1.65E-07	-6.01E-07	3.13E-03	7.97E-08	2.08E-06	-3.91E-05	-5.58E-07
Entrance and street Sidewalk	-2.42E-07	-1.43E-07	6.17E-03	-2.06E-07	-5.17E-04	-3.66E-04	1.87E-06
Walking paths - crusher fines	-3.32E-07	2.83E-06	-7.65E-03	3.47E-06	1.25E-04	3.19E-05	1.88E-06
Concrete Curb, Walking Path, Sidewalk	-4.02E-08	-6.36E-07	4.40E-03	-1.12E-06	-1.61E-05	-1.83E-04	-3.84E-06
Total Concrete, Colored, Brick, Stamped, Cobblestone	-3.30E-07	-4.34E-07	7.47E-03	-5.90E-06	-2.84E-04	-7.32E-04	3.08E-06
Total Concrete Non Vehicular	-8.97E-09	-5.72E-07	1.23E-03	-1.47E-07	-1.81E-04	-3.39E-05	-1.16E-06
Total Concrete, Driveway, Slab	-1.70E-06	1.69E-06	1.51E-02	8.40E-06	-3.71E-04	9.30E-04	-6.09E-06
Total Concrete	-1.81E-07	-6.95E-07	4.79E-03	4.53E-07	-7.06E-05	-9.43E-06	-1.98E-06

2.5 Future Research

The objective of this statistical analysis is to determine the effects of LL's on student outcomes. A future consideration would involve investigating the social and economic impacts of these student outcomes in adulthood. These impacts would involve employment, career development such as salaries, economic growth and reduced crime. By associating student outcomes to such impacts, it allows for a monetization of the impacts on society, which can be used as an effective measure to compare against the costs of building a LL. Society is very much influenced by the development of younger generations, and as such, linking improvements in student outcomes with improvements in society is a worthwhile endeavor.

3. Additional Quantitative Analysis

3.1 Overview

The additional quantitative analysis of this report reflects the analysis that is conducted to be distinct from the statistical analysis. This analysis contains two components: (1) Financial Valuations and (2) Site Surface Analysis, which will be further discussed in the following subsections.

This analysis was also intended to assess financial implications involving financial costs and revenue/avoided costs across multiple dimensions - broadly named Return on Investment (ROI) components for this effort. The capital costs along with maintenance costs, were to be compared with any monetized benefits which result from the LL's project. However, the majority of benefits stemming from student outcomes cannot be monetized immediately. Such benefits of attendance and test scores are factors that will affect employment and earnings which can only be monetized years later. This opens up opportunities for future research as addressed earlier in this report. Regarding maintenance costs, the data across the years has been very inconsistent, with spending appearing to dwindle. As such valuation of maintenance costs were not conducted. Regardless of the challenges in valuations, valuing any costs and revenues that could be monetized are still beneficial. Which is why this report includes the assessment of financial components, which is discussed in the following section.

3.1.1 Financial Valuations Overview

As a result of the LL project, there are several related financial components that are helpful to evaluate. Components such as capital costs, revenues from garden produce, and additional funding due to increase in pupil membership.

Capital Cost Overview

The capital costs were financed across three periods from three different sources. As previously mentioned in this report, 99 schools experienced a LL's transformation between 2000-2012. From 2000-2003, the funding source came from a private/public partnership between the district and private organizations. In the following period of 2004-2008, funding was provided through a general obligation bond. Lastly, from 2009-2012, funding was provided by another general obligation bond. Funding allocations for each LL were provided by DPS. The capital costs considerations are intended to give an idea of the investment needed to implement LL's in order to receive all their benefits.

Revenue from Garden Produce Overview

The revenues from garden produce are regarding a school garden program that exists in tandem with the LL's project. Due to the redevelopment of the school landscape, the schools can grow their own produce for the purpose of lunch sales. This not only improves the health of the students, but it also generates revenue for the schools.

Additional Funding from Pupil Membership Overview

Additional funding related to pupil membership involves the funding that schools receive from the state based on their total pupil membership. Schools that expect increases in enrollment will naturally need more funding. The Colorado Department of Education accounts for this increase by assuming a per student funding amount and appropriating the funds accordingly on the basis of total student enrollment. By retrieving the increase in pupil membership found in the statistical analysis, a per student funding value can be applied to identify the additional funding.

3.1.2 Site Surface Analysis Overview

The site surface analysis focuses on observing detailed Geographic Information System (GIS) spatial data on the pre-LL surface profiles to be compared with their post transformation surface profile. This pre/post comparison is based on two measures: the change in (1) urban heat island effect and (2) carbon sequestration. Regarding the urban heat island effect, the ambient temperatures and their effects on mortality are calculated for the sites before and after redevelopment. This is to determine the net effect on ambient temperature and the mortality related to temperature as a result of the LLs transformation. Carbon sequestration involves comparing the carbon sequestered by the site surfaces pre- and post-transformation. This will indicate the effects of a LL's transformation on carbon sequestered, and consequently the reduction of carbon in the school area.

3.2 Data

Data For Financial Valuations

As the financial valuations involve three various components of capital costs, revenues from garden produce and additional funding from pupil membership, the data forms and sources also vary.

Capital Cost Data

The capital costs of the 99 schools were segmented in three batches in tandem with the funding periods. Funding allocations for each LL were provided by DPS. Table 8 outlines the funding allocations according to the funding periods, the sources, and the number of schools built in each period.

Table 8: Funding Allocation Periods

Funding Period	Funding Source	Number of Schools Built
2000-2003	Private/Public Partnership	21
2004-2008	1st Bond	27
2009-2012	2nd Bond	51

Revenues From Garden Produce Data

The revenues from garden produce are determined from produce sales from participating schools from 2011-2019. This data was also received from DPS. Table 9 displays the Annual total revenues in 2022 dollars, along with the schools participating each year.

Table 9: Annual Revenues for School Produce

Year	# of Schools Participating	Total Revenues
2011	13	$2,010
2012	15	$1,574
2013	13	$1,323
2014	17	$1,693
2015	13	$1,918
2016	13	$1,480
2017	17	$2,304
2018	12	$1,499
2019	7	$2,250

Additional Funding From Pupil Membership Data

The additional funding for pupil membership is derived from the per pupil funding provided by the state. Data on per pupil funding was collected from CDE documentation on Colorado School Finance and Categorical Program Funding. An average per pupil funding across all districts for the year of 2018 is estimated at $7,662 and reflected at $8,827 when inflated to 2022 dollars.

Data for Site Surface Analysis

The site surface analysis involves measuring the change in ambient temperature and carbon sequestered from the site surface transformations of each LL site. The data required for calculating both measures are the site surface profiles of each school yard pre- and post-transformation. This entails a categorization of surface types and features and their associated surface area coverage and counts. The site surface areas and counts were extracted through the use of GIS on schoolyard maps of the pre and post environments by Professor Peter Anthamatten of University Colorado Denver Department of Geography and Environmental Sciences and his team of researchers. Table 10 displays the various site surfaces and features that are measured pre- and post-LL.

Table 10: Site Surfaces and Surface Types

Site Surfaces/Features	Surface Type
Parking Lot	Asphalt
Front Sidewalks	Concrete
Walks	Concrete
Front Lawn	Low Vegetation
Hard Surface Play	Asphalt
Pea Gravel	Gravel
Grass Play	Low Vegetation
Sports Play	Low Vegetation
Garden	Low Vegetation
Native/Landscape Area	Low Vegetation
# Trees	Trees
Tree Canopy SQFT	Trees
Play Equipment	Metal/Plastic
Landscape/Boulders/Walls	Stone
Walking Path Crusher Fine	Gravel

3.3 Methodology

Financial Valuation Methodology

The methodology of the financial valuations of this analysis entail a series of various calculations pertaining to the three components of capital costs, revenues from garden produce, and additional funding from pupil membership.

Capital Cost Methodology

Regarding capital costs, the funding for each school according to each year of completion is available. Inflation factors derived from CPI data were applied to each value in order to reflect the cost of each school in 2022 dollars. Once these costs were determined, they were aggregated by funding period, as well as a final total. The total capital expenditures were used further with the number of schools and total square feet of all school yards to determine a cost per school and square footage.

Revenue From Garden Produce Methodology

The revenues from garden produce were calculated in a similar manner as capital costs. The annual revenues were inflated by CPI derived inflators. Once inflated, values were divided by the number of schools participating each year to produce cost per school figures. The inflated annual values and cost per school figures were both aggregated to produce total valuations.

Addition Funding From Pupil Membership Methodology

The additional funding from pupil membership was calculated by taking the product of the inflation adjusted per pupil funding and estimated annual pupil enrolment. The estimated annual pupil enrolment is represented by the increase in pupil membership due to LL implementation, which was estimated in the longitudinal analysis of this report.

Site Surface Analysis Methodology

The different site surfaces were evaluated to understand the effect of changes in land cover across the schools in the South West region. The list of schools covered as a part of this analysis includes:

- Barnum
- Castro
- College view
- Doull
- Force
- Godsman
- Goldrick
- Gust
- Johnson
- Kaiser
- Knapp
- Mckinley-Thatcher
- Munroe
- Newlon
- Sabin
- Schenck (CMS)
- Schmitt
- Traylor
- Valverde

School CAD files for the years 2017 and 2018 were used to showcase the area coverage differences for the following feature types, which were then assessed for their Solar Reflectance Values (for impervious surfaces) and heat conductance / shading capacity (for vegetation):

- Front sidewalk
- Walks
- Front lawn
- Hard surface play
- Pea gravel
- Grass play
- Sports play
- Garden
- Native / landscape area
- Trees and canopy coverage
- Play equipment
- Landscape / boulders / walls
- Walking path - fine crusher

The mapping of these surface types to impervious and vegetative cover have been shown in Table 10. Solar reflectance Index represents a combination of albedo and thermal emittance levels for impervious surfaces that are responsible for the ambient temperature felt around the school area. These values are extracted from a combination of scientific literature for different ground cover types (Alchapar et al., 2014; Madhumathi et al., 2018; Radhi et al., 2014; Santamouris et al., 2011; Tran et al., 2009; Uzarowski et al., 2018), and converted into an ambient air temperature change as the land cover changes (Guan et al., 2011). Similarly, an increase in vegetative cover is responsible for a change in the heat exchange, absorption and conduction.

Ambient temperatures play an important role in this analysis because of the increased impact and frequency of heat waves across North America, sometimes resulting in large numbers of premature deaths. These events may be more frequent and severe in the future due to climate change. As a part of the analysis, these changes in climatic conditions are accounted for using location specific (mapped to 25 square km cells) temperature forecasts used from the CanESM2 model by the Canadian Centre for Climate Modelling (CCCma, 2017). The CanESM2 model represents the Canadian contribution to the IPCC Fifth Assessment Report (AR5). The Representative Concentration Pathway (RCP) used for this analysis is 4.5, a long term scenario where global emissions of greenhouse gasses, short-lived species, and land-use-land-cover stabilizes radiative forcing at 4.5 Watts per meter squared or approximately 650 ppm CO2-equivalent by 2100. The forecasted temperature data is assessed on a monthly basis through the study period, with a lens to analyze the pre-post land cover with changing temperatures.

Investing in a cool or green vegetative surface reduces the severity of extreme heat events by controlling the level of heat absorbed, radiated, conducted, and emitted into the surrounding area, i.e. affecting the ambient temperature. Cooling effects from better choices in vegetative cover and lighter surfaces can work towards sufficiently reducing heat stress-related fatalities, strokes and illnesses during extreme heat wave events, thereby a benefit to the community. Trees also provide a cooling effect due to the shade and respite provided by the increased canopy coverage. This is especially beneficial for play areas when children spend time outdoors during the day. The effects of green space are therefore accounted for proportionally as the land cover changes before and after learning landscapes to estimate before and after ambient temperatures surrounding the landscape area (Parshall et al., 2011; Sailor & Hagos, 2011, Ibsen et al., 2022). The incremental difference in temperature is shown for each school as a part of the results section in Site Surfaces Analysis.

The environmental impacts covered as a part of the site surface analysis include the level of carbon sequestration, storage capacity, and the change in criteria air contaminants deposited on vegetative surfaces (iTree Landscape, 2022). This occurs through the accumulation of carbon in above and below ground plant biomass as well as in the soil beneath the vegetation as soil organic carbon. Carbon sequestration values are reported as a rate of mass over a given unit of time for a unit of area. The greater the area that is covered in vegetation and the longer the vegetation persists, the greater the amount of carbon that is sequestered, with trees having the maximum sequestration potential. The rate at which carbon is sequestered depends on the type of vegetation. This research has been gathered using a combination of literature from the iTree tool as well as research for shorter plants and shrubberies, and turf. Larger plants sequester more carbon as they have more above and below ground biomass both of which store carbon. Carbon also accumulates in the soil as the vegetation grows. Literature has also shown there to be different rates of sequestration depending on whether or not the vegetation is managed or unmanaged, with unmanaged vegetation having higher sequestration rates due to the emissions associated with management practices. This study uses estimates for managed turf over a study period of 40 years.

3.4 Results

This section of the report will discuss the results of the additional quantitative analysis for the two components financial valuation and site surface analysis.

Financial Valuation Results

The financial valuations of capital costs, revenue from garden produce and additional per pupil funding are presented as follows.

Capital Cost Results

Table 11 describes the capital costs in each funding period. The capital costs by period are approximately $8.9 million in the first period, $14.7 million in the second, and $36.8 million in the last. Table 12 reflects the total capital costs. Total costs are approximately $60 million, total costs per LL schools are approximately $630,000, with costs per square foot amounting to $2.23.

Table 11: Learning Landscape Capital Costs By Period

Learning Landscapes Periods	Capital Costs (2022 Dollars)
2000-2003	$8,920,724
2004-2008	$14,741,828
2009-2012	$36,818,629

Table 12: Learning Landscapes Cost Totals

Total Capital Costs	$60,481,181
Cost Per School	$630,012
Cost Per \SQFT	$2.23

Revenues From Garden Produce Results

Table 13 shows the total revenues calculated from the annual revenues data. Total revenues amount to approximately $16,000 with cost per school approximately $1,300.

Table 13: Total Revenues Calculated From Garden Produce

Year	# of Schools Participating	Total Revenues	Revenues Per School
2011	13	$2,010	$155
2012	15	$1,574	$105
2013	13	$1,323	$102
2014	17	$1,693	$100
2015	13	$1,918	$148
2016	13	$1,480	$114
2017	17	$2,304	$136
2018	12	$1,499	$125
2019	7	$2,250	$321
Total	**120**	**$16,051**	**$1,304**

Additional Funding From Pupil Membership Results

When applying the per pupil funding value to the average increase in pupil membership of 152 from the longitudinal analysis, the results are as follows in Table 14. The per pupil funding of $8,827 when applied to an annual increase in 152 students enrolled amounts to an annual funding for additional enrollment of $1,341,777.

Table 14: Average Annual Additional Funding Of Pupil Membership

Per Pupil Funding (2018 Dollars)	$7,662
Per Pupil Funding (2022 Dollars)	$8,827
Total Additional FUnding	$1,341,777

Sites Surface Analysis Results

The inclusion of learning landscape benefits the community by reducing ambient temperatures and sequestering carbon and criteria air contaminants. Across different schools there is a change in ambient temperature ranging between 9 - 27 degrees fahrenheit observed during the peak of summer season (estimated to be between the middle of May to August every year). Additionally, there is also significant carbon sequestration and storage across the landscapes recorded in Table 16.

Table 15: Learning Landscape Effect on Ambient Temperature

School	Pre impervious (%)	Post impervious (%)	Pre vegetated (%)	Post vegetated (%)	Additional trees	Change in ambient temperature (°F)
BARNUM	65%	49%	35%	51%	33	27
CASTRO	34%	27%	66%	73%	28	9
COLLEGE	86%	50%	14%	50%	68	16

VIEW						
DOULL	37%	28%	63%	72%	80	11
FORCE	85%	33%	15%	67%	67	16
GODSMAN	74%	51%	26%	49%	17	13
GOLDRICK	74%	51%	26%	49%	41	13
GUST	91%	48%	9%	52%	84	18
JOHNSON	74%	58%	26%	42%	9	18
KAISER	76%	35%	24%	65%	52	13
KNAPP	61%	48%	39%	52%	37	9
MCKINLEY-T HATCHER	87%	56%	13%	44%	28	22
MUNROE	78%	44%	22%	56%	31	13
NEWLON	90%	46%	10%	54%	55	16
SABIN	36%	24%	64%	76%	29	9
SCHENCK (CMS)	88%	60%	12%	40%	46	13
SCHMITT	85%	48%	15%	52%	30	18
TRAYLOR	79%	54%	21%	46%	89	22
VALVERDE	81%	58%	19%	42%	34	18

Table 16: Learning Landscape Effect on Sequestration over 40 years

School	Change in vegetation (sqft)	Additional trees	Carbon sequestration (tons)	Air pollutant sequestration (lbs)
BARNUM	8,400	33	376	39
CASTRO	7,170	28	319	33
COLLEGE VIEW	42,693	68	779	168
DOULL	16,248	80	912	81
FORCE	122,802	67	777	443
GODSMAN	36,410	17	198	130
GOLDRICK	30,653	41	470	118
GUST	60,054	84	963	233
JOHNSON	24,947	9	105	89
KAISER	99,713	52	604	359
KNAPP	30,877	37	425	118
MCKINLEY-THATCHER	34,272	28	323	127
MUNROE	53,411	31	359	193
NEWLON	71,777	55	634	264
SABIN	24,479	29	333	93
SCHENCK (CMS)	35,680	46	528	137
SCHMITT	74,495	30	350	265

TRAYLOR	21,724	89	1,015	103
VALVERDE	27,559	34	390	105

Scaling Results From South West Schools To Reflect District Impacts

With the interest of understanding district level impacts, the supplementary analysis of the southwest schools are used to provide a scaled up analysis to infer impacts to the district as a whole. When incorporating the results from the 19 southwest schools in DPS a general approach is used to scale up the results to reflect impacts across the district. Concerning UHI effects, the change in ambient temperatures of the 19 schools are averaged to reflect an average change in temperature that can be attributed to each of the remaining 88 schools in the district. Regarding carbon sequestered, the total value of carbon sequestered is summed across the 19 schools and is multiplied by a linear scale factor of 5.21 based on the proportion of the 19 schools to the 99 schools in the entire district. The scaled results for both UHI and carbon sequestered impacts can be seen in Table 17.

Table 17: Scaled Results of UHI and Carbon Sequestration Impacts

AVG Change in Temp Per School (°F)	15
Carbon Sequestration Across District (tons)	51,371
Air Pollution Sequestration Across District (lbs)	16,141

4. Appendix

Alchapar, N., Correa, E. N., Canton, M.A. (2014). Classification of building materials used in the urban envelopes according to their capacity for mitigation of the urban heat island in semiarid zones. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0378778813006580

Amoly E., Dadvand P, et al. (2014). Green and Blue Spaces and Behavioral Development in Barcelona Schoolchildren: The BREATHE Project. Environmental Health Perspectives, 122(12). Doi: 10.1289/ehp.1408215.

Anthamatten, P., et al. (2014). A Microgeographic Analysis of Physical Activity Behavior Within Elementary School Grounds. American Journal of Health Promotion, 28(6). DOI: 10.4278/ajhp.121116-QUAN-566

Anderson, G. & Bell, M. (2011). Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. Environmental Health Perspectives 119: 210–218. Retrieved from: https://www.ncbi.nlm.nih.gov/pubmed/21084239

Basu, R., Feng, W.-Y., & Ostro, B. D. (2008). Characterizing temperature and mortality in nine California counties. Epidemiology: 19 (1): 138–145. Retrieved from: https://www.ncbi.nlm.nih.gov/pubmed/1809142

Bates, C. R., Bohnert, A. M., & Gerstein, D. E. (2018). Green Schoolyards in Low-Income Urban Neighborhoods: Natural Spaces for Positive Youth Development Outcomes. Frontiers in psychology, 9, 805. https://doi.org/10.3389/fpsyg.2018.00805

Brink, L. et al. (2010). Influence of Schoolyard Renovations on Children's Physical Activity: The Learning Landscapes Program. American Journal of Public Health, 100(9). DOI: 10.2105/AJPH.2009.178939

Brookmeyer, K. A., Fanti, K.A., & Henrich, G. C. (2006). Schools, parents, and youth violence: A multilevel, ecological analysis. Journal of Clinical Child and Adolescent Psychology, 35, 504–514.

Browning, Matthew H.E.M.; Rigolon, Alessandro (2019). School Green Space and Its Impact on Academic Performance: A Systematic Literature Review. International Journal of Environmental Research and Public Health, 16(3). doi:10.3390/ijerph16030429

Bundy, A. (2017). Sydney Playground Project: A Cluster-Randomized Trial to Increase Physical Activity, Play, and Social Skills. Journal of School Health, 87(10). Doi: 10.1111/josh.12550

Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-differences with multiple time periods. *Journal of Econometrics*, *225*(2), 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Canadian Centre for Climate Modelling and Analysis (CCCma). (2017). CanESM2 model: The Fourth Generation Global Climate Model. Retrieved from: http://climate-modelling.canada.ca/data/data.shtml

Card, D., & Krueger, A. (1993). Minimum wages and employment: A case study of the fast food industry in New Jersey and Pennsylvania. *The American Economic Review*. https://doi.org/10.3386/w4509

Chawla, L. 2015. Benefits of Nature Contact for Children. In: Nasar, JL (ed.), J Plan Lit 30(4): 433–452. DOI: https://doi.org/10.1177/0885412215595441

Colorado Department of Education. (2016). *Understanding Colorado School Finance And Categorical Program Funding*. Retrieved November 24, 2022, from https://spl.cde.state.co.us/artemis/edserials/ed55067internet/ed550672010internet.pdf

Colorado Department of Education. (n.d.). *Attendance information*. CDE. Retrieved November 23, 2022, from https://www.cde.state.co.us/cdereval/truancystatistics

Colorado Department of Education. (n.d.). *District and School Performance Framework Results*. CDE. Retrieved November 23, 2022, from http://www.cde.state.co.us/accountability/performanceframeworkresults

Colorado Department of Education. (n.d.). *Mobility / Stability Statistics*. CDE. Retrieved November 23, 2022, from https://www.cde.state.co.us/cdereval/mobility-stabilitycurrent

Columbia Mailman School of Public Health. (n.d.). *Difference-in-difference estimation*. Columbia Public Health. Retrieved November 23, 2022, from https://www.publichealth.columbia.edu/research/population-health-methods/difference-difference-estimation

Curriero, F. C., Heiner, K. S., Samet, J. M., Zeger, S. L., Strug, L., & Patz, J. A. (2002). Temperature and mortality in 11 cities of the eastern United States. Retrieved from: http://aje.oxfordjournals.org/content/155/1/80.full.pdf

Centers for Disease Control and Prevention (CDC). (2015). National Vital Statistics Reports. Volume 66, Number 6. Retrieved from: https://www.cdc.gov/nchs/data/nvsr/nvsr66/nvsr66_06.pdf

Catterall, J, and Stern, D. (1986). The Effects of Alternative School Programs on High School Completion and Labor Market. Educational Evaluation and Policy Analysis, 8(1); 77-86. Retrieved: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.877.8642&rep=rep1&type=pdf

Davis, J.N., Pérez, A., Asigbee, F.M. et al. School-based gardening, cooking and nutrition intervention increased vegetable intake but did not reduce BMI: Texas sprouts - a cluster randomized controlled trial. Int J Behav Nutr Phys Act 18, 18 (2021). https://doi.org/10.1186/s12966-021-01087-x

Eide, E., and Showalter, M. (2008). Does Improving School Quality Reduce The Probability Of Unemployment? Contemporary Economic Policy. Doi: 10.1093/cep/byi042

Engelen, L., et al. (2013). Increasing physical activity in young primary school children — it's child's play: A cluster randomised controlled trial. Preventative Medicine, 56(5). Doi: 10.1016/j.ypmed.2013.02.007

Freudenberg, N., and Ruglis, J. (2007). Reframing School Dropout as a Public Health Issue. Preventing Chronic Disease, 4(4).

Getter, K.L., Rowe, D.B., Robertson, G.P., Gregg, B.P., & Andersen J.A. (2009). Carbon sequestration potential of extensive green roofs. Environmental Science & Technology. 43. 7564-7570. Retrieved from: https://pubs.acs.org/doi/abs/10.1021/es901539x

Gopalakrishnan, V., Hirabayashi, S., Ziv, G., & Bakshi, B.R. (2018). Air quality and human health impacts of grasslands and shrublands in the United States. Atmospheric Environment. 182. 193-199. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S1352231018301936?via%3Dihub

Grimmond, C. S. B., Guang-Heng, N., Sun, T. (2016). How do green roofs mitigate urban thermal stress under heat waves?. Retrieved from: https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2016JD024873

Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., Lavigne, E., de Sousa Zanotti Stagliorio Coelho, M., Leone, M., Pan, X., Tong, S., Tian, L., Kim, H., Hashizume, M., Honda, Y., Guo, Y. L., Wu, C. F., Punnasiri, K., Yi, S. M., Michelozzi, P., … Williams, G. (2014). Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidemiology (Cambridge, Mass.), 25(6), 781–789. Retrieved from: https://www.ncbi.nlm.nih.gov/pubmed/25166878

Hart, C.N., et al. (2010) Early Patterns of Food Intake in an Adolescent Weight Loss Trial as Predictors of BMI Change. Eat Behav. 2010 Dec; 11(4): 217–222.doi: 10.1016/j.eatbeh.2010.05.001

Hjorth, C.F., Bilgrav, L., Frandsen, L.S. et al. Mental health and school dropout across educational levels and genders: a 4.8-year follow-up study. BMC Public Health 16, 976 (2016). https://doi.org/10.1186/s12889-016-3622-8

Ibsen, P. C., Jenerette, G. D., Dell, T., Bagstad, K. J., & Diffendorfer, J. E. (2022). Urban landcover differentially drives day and nighttime air temperature across a semi-arid city. *Science of The Total Environment*, *829*, 154589. https://doi.org/10.1016/j.scitotenv.2022.154589

Janhall, S. (2016). Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmospheric Environment. 105(2015): 130-137. Retrieved from: https://www.sciencedirect.com/science/article/pii/S1352231015000758?via%3Dihub

Kuronuma, T., Watanabe, H., Ishihara T., Kou, D., Toushima, K., Ando, M., & Shindo, S. (2018). CO2 payoff of extensive green roofs with different vegetation species. Sustainability. 10(7). Retrieved from: https://www.mdpi.com/2071-1050/10/7/2256

Khan, M., & Bell, R. (2019). Effects of a School Based Intervention on Children's Physical Activity and Healthy Eating: A Mixed-Methods Study. International journal of environmental research and public health, 16(22), 4320. https://doi.org/10.3390/ijerph16224320

Kuo et al. (2018). Might School Performance Grow on Trees? Examining the Link Between “Greenness” and Academic Achievement in Urban, High-Poverty Schools

Kweon, B.-S., Ellis, C. D., Lee, J., & Jacobs, K. (2017). The link between school environments and student academic performance. Urban Forestry & Urban Greening, 23, 35–43

Lineberger, S., and Zajicek, J. (2000). School Gardens: Can a Hands-on Teaching Tool Affect Students' Attitudes and Behaviors Regarding Fruit and Vegetables? HortTechnology, 10(3). doi:10.21273/HORTTECH.10.3.593

Li, M. (2005). High school completion and future youth unemployment: new evidence from High School and Beyond. doi:10.1002/jae.817

Liebig, M.A., Schmer, M.R., Vogel, K.P., & MItchell, R.B. (2008). Soil carbon storage by switchgrass grown for bioenergy. BioEnergy Research. 1. 215-222. Retrieved from: https://link.springer.com/article/10.1007/s12155-008-9019-5

Louise Chawla, Kelly Keena, Illène Pevec, Emily Stanley, Green schoolyards as havens from stress and resources for resilience in childhood and adolescence, Health & Place, Volume 28, 2014, Pages 1-13, ISSN 1353-8292, https://doi.org/10.1016/j.healthplace.2014.03.001.

Leuven, J., Rutenfrans, A., Dolfing, A. G., & Leuven, R. (2018). School gardening increases knowledge of primary school children on edible plants and preference for vegetables. Food science & nutrition, 6(7), 1960–1967. https://doi.org/10.1002/fsn3.758

Morgan, Philip & Warren, Janet & Lubans, David & Saunders, Kristen & Quick, Garbrielle & Collins, Clare. (2010). The impact of nutrition education with and without a school garden on knowledge, vegetable intake and preferences and quality of school life among primary-school students. Public health nutrition. 13. 1931-40. 10.1017/S1368980010000959

Madhumathi, A., Subhashini, S., & VishnuPriya, J. (2018). The urban heat island effect its causes and mitigation with reference to the thermal properties of roof coverings. International Conference on Urban Sustainability: Emerging Trends, Themes, Concepts and Practices. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3207224

Maas J, Verheij RA, Groenewegen PP, et alGreen space, urbanity, and health: how strong is the relation?Journal of Epidemiology & Community Health 2006;60:587-592.

Merrick, M. et al. (2019). Vital Signs: Estimated Proportion of Adult Health Problems Attributable to Adverse Childhood Experiences and Implications for Prevention — 25 States, 2015–2017. MMWR Morb Mortal Wkly Rep; 68(44): 999–1005. doi: 10.15585/mmwr.mm6844e1

Moharejani, A. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete.Retrieved from: https://www.ncbi.nlm.nih.gov/pubmed/28412623

Nancy Cotugna, Carolyn K. Manning & James DiDomenico. (2012). Impact of the Use of Produce Grown in an Elementary School Garden on Consumption of Vegetables at School Lunch, Journal of Hunger & Environmental Nutrition, 7:1, 11-19, DOI: 10.1080/19320248.2012.649668

Peters, K, Elands, B and Buijs, A. 2010. Social interactions in urban parks: Stimulating social cohesion? Urban For Urban Green 9(2): 93–100. DOI: https://doi.org/10.1016/j.ufug.2009.11.003

Qian, Y., Follet, R.F., & Kimble, J.M. (2010). Soil organic carbon input from urban turfgrasses. Soil Science Society of America Journal. 74:366-371. Retrieved from: https://acsess.onlinelibrary.wiley.com/doi/abs/10.2136/sssaj2009.0075

Radhi, H., Fikry, F., & Sharples, S. (2013). Impacts of urbanisation on the thermal behaviour of new built up environments: A scoping study of the urban heat island in Bahrain. Landscape and Urban Planning, 113, 47–61. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0169204613000200?via%3Dihub

Radhi, H., Assem, E., & Sharples, S. (2014). On the colours and properties of building surface materials to mitigate urban heat islands in highly productive solar regions. Building and Environment. 72(2014): 162-172. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0360132313003193?via%3Dihub

Ramsadala, G., Rikke, G., and Wynn, R. (2013). Dropout and early unemployment. International Journal of Educational Research, 62; 75-86. Doi: 10.1016/j.ijer.2013.06.011

Riddell, W. Craig; Song, Xueda (2011) : The impact of education on unemployment incidence and re-employment success: Evidence from the US labour market, IZA Discussion Papers, No. 5572, Institute for the Study of Labor (IZA), Bonn, http://nbn-resolving.de/urn:nbn:de:101:1-201104133943

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Solar Energy, 85(12), 3085–3102. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0038092X10004020

Selhorst, A. & Lal, R. (2012). Net carbon sequestration potential and emissions in home lawn turgrasses of the United States. Environmental Management. 51: 198-208. Retrieved from: https://link.springer.com/article/10.1007/s00267-012-9967-6

Sharma, A., Woodruff, S., Budhathoki, M. (2016). Role of green roofs in reducing heat stress in vulnerable urban communities - a multidisciplinary approach. Retrieved from: https://www.semanticscholar.org/paper/Role-of-green-roofs-in-reducing-heat-stress-in-Sharma-Woodruff/544128ad67b8823b46be71d6d23a5c203f7be286

Sivarajah, S., Smith, S. M., & Thomas, S. C. (2018). Tree cover and species composition effects on academic performance of primary school students. PloS one, 13(2), e0193254.

Stevenson, K., et al. (2020) A national research agenda supporting green schoolyard development and equitable access to nature. Science of the Anthropocene, 8(1). doi:10.1525/elementa.406

Stevenson, KT, Peterson, MN, Bondell, HD, Mertig, AG and Moore, SE. 2013. Environmental, institutional, and demographic predictors of environmental literacy among middle school children. Patterson RL, editor. Plos One 8(3): e59519. DOI: https://doi.org/10.1371/journal.pone.0059519

Tran, N., Powell, B., Marks, H., West, R., & Kvasnak, A. (2009). Strategies for Design and Construction of High-Reflectance Asphalt Pavements. Transportation Research Record, 2098(1), 124–130. https://doi.org/10.3141/2098-13. Retrieved from: https://journals.sagepub.com/doi/abs/10.3141/2098-13

U.S. Census Bureau. (2017). National Population Totals and Components of Change 2010-2017. Retrieved from: https://www.census.gov/data/tables/2017/demo/popest/nation-total.html

U.S. Environmental Protection Agency. (2010). Guidelines for Preparing Economic Analyses, Appendix B: Mortality Risk Valuation Estimates. United States Government. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

Uzarowski, L., Rizvi, R., & Manolis, S. (2018). Reducing Urban Heat Island Effect by Using Light Coloured Asphalt Pavement. Retrieved from https://www.tac-atc.ca/sites/default/files/conf_papers/uzarowskil_-_reducing_urban_heat_island_effect_using_lcap.pdf

Whittinghill, L. J., Rowe, B. D., Schutzki, R., & Cregg, B.M. (2014). Quantifying carbon sequestration of various green roof and ornamental landscape systems. Landscape and Urban Planning. 123: 41-48. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0169204613002296?via%3Dihub

Zirkle, G., Lal, R., & Augustin, B. (2011). Modeling carbon sequestration in home lawns. Horticultural Science. 46(5): 808-814. Retrieved from: https://www.researchgate.net/publication/282543110_Modeling_Carbon_Sequestration_in_Home_Lawns

Appendix B
Learning Landscapes Literature Review

Introduction

Green spaces and access to nature have numerous benefits to society. By greening schoolyards, communities would be able to provide safe, accessible, natural areas, a larger educational space, and thereby resources that benefit the school and surrounding community. Learning Landscapes school-yard designs actively engage the school community throughout the planning, design, construction, and maintenance of the yard. It engages the local community throughout construction and maintenance through active volunteer days, which is responsible for developing a sense of ownership and civic pride within the community. As a part of this project, every elementary Denver Public Schoolyard has been transformed into a vibrant and healthy play space. These investments are expected to show additional physical activity and socialization skills amongst the children. Educational elements across the schoolyards include fractions, historical timelines, common words, and quotes to help the students learn while they play. Green areas provide benefits in terms of improved health and wellness, learning, and a myriad of other benefits listed in the figure below.

A literature review was conducted with the aim of supporting an econometric analysis of the outcomes of Learning Landscapes. A list of outcomes was determined from the Children & Nature Network's list of benefits obtained from greening schoolyards. The list of final reviewed outcomes were narrowed down by reviewing the possibility of quantification and ease of fit into econometric modeling. The Web of Science, Children & Nature Network Research Library, and Google Scholar were all used to conduct searches for literature using key terms related to the targeted outcomes of Learning Landscapes. A list of 33 papers of interest were chosen for inclusion as examples of the state of the literature. The papers reviewed were selected according to the presence of quantitative and statistical analyses, in order to find gaps that could be filled with the subsequent econometric analysis. The absence of coverage of certain outcomes in this literature review does not reflect an absence of qualitative literature, nor does it suggest it will not be the subject of further review. Absence of coverage suggests the team did not find quantitative analyses of high quality that supported certain outcomes.

Green Space Features & Programming included in Learning Landscapes

The features and interventions covered as a part of learning landscapes may be broadly categorized under Learning interventions, Health and Wellness Interventions, Environmental Interventions, and Community Interventions. The distinctive schoolyard design elements consist of

- Community gateways and gathering spaces
- Public artworks
- Age-appropriate play equipment
- Grass playing fields
- Colored structured and unstructured asphalt games
- Custom shade structures

- Vegetable gardens
- Habitat areas/nature play

Some of the effects expected from the design elements include

- Increased time spent outdoor by children through learning and play activities,
- Community involvement in the construction and maintenance of the yard,
- Expected educational outcomes that set students up to succeed better
- Increased access to fresh produce in the cafeteria is expected to benefit students and the school
- Increased environmental benefits from greening such as ambient temperature reductions and habitat restoration.

Learning Landscapes Outcomes

There are three categories of impacts that are expected to be evaluated as a part of the learning landscapes investments: Learning, Health & Wellness, and Environment. The 'Community' category of outcomes, such as family engagement and community cohesion represented a large gap in terms of quantitative and statistical research. This will be reviewed in the subsequent quantitative analysis. Research by Stevenson et al. (2020) has identified key areas of improvement that include academic performance, physical activity, mental health, beneficial play, socio-economic skills, nutrition education, water management, shade canopy, wildlife habitat (pollination), environmental literacy, community place-making, and family engagement. The key components of interest in this literature review are as follows:

- Learning Outcomes
  - Increased student attendance & principal referrals
  - Dropout rates
  - Enrollment rates
  - Improved academic achievement
  - Long term unemployment
- Health & Wellness Outcomes
  - Increased play and physical health
  - Student mental health - improved mood
  - School lunch sales
  - Nutrition
- Environmental Outcomes
  - Composting programs
  - Urban heat island and temperature impacts
  - Carbon sequestration
  - Pollination/habitat creation benefits
- Community Outcomes
  - Vandalism & graffiti reductions
  - Property Value

Learning Outcomes

Learning outcomes that have been reviewed are increased student attendance (reduction in absenteeism), increased achievement, and related equity considerations. There is broad evidence to support the impact of schoolyard improvements on these learning outcomes, but specific outcomes are lacking in research. Importantly, dropouts, enrollment, and unemployment are not commonly tied to schoolyard improvements in the literature. It is expected that the econometric analysis will fill these gaps.

Increased Student Attendance & Principal Referrals

It is expected that schoolyard improvements will lead to decreased student absenteeism and principal referrals. A paper by Brookmeyer, Fanti, and Henrich (2006) used data from the National Longitudinal Study of Adolescent Health to investigate the joint contribution of parents and schools on violent behavior across 6,397 students enrolled in 125 schools. On the school level, the study examined the main and interactive effects of parents and school connectedness on changes in student violent behavior over time, and connectedness as a buffer against violence exposure/behavior. The study showed a positive correlation between school climate and attendance rates, a negative correlation with school drop-out rates. As well, the study showed that larger classroom sizes were associated with a more negative school climate. A study by Shochet et al. (2006) studies the relation between school connectedness and mental health symptoms in adolescents. They took a sample of 2000 students between the ages of 9-14 to understand the correlation between mental health symptoms and school connectedness. The study found that reduced connectedness predicted depressive symptoms a year after testing, anxiety symptoms, and general functioning while controlling for prior symptoms.

An exploratory study by Ingul et al. (2011) investigated the relative importance of different risk factors on absenteeism in Norway. The study assessed 865 Norwegian high schools and assessed risk factors associated with the student, school, community, and family in relation to student absenteeism. In addition to prohibitory health factors, school factors including poor school climate where students feel unsafe/unaccepted or unvalued at school, low school connectedness increases the prevalence of school absenteeism. Finally, a study by Bruns et al (2004) investigated a reduction of out-of-school suspension rates in the presence of school-based mental health clinicians. The study covers eighty-two elementary schools, with half as training, and half as a testing set; it uses a stepwise linear regression to predict out-of-school suspension rates given student enrollment, poverty rates, attendance rates between the treatment and control schools. Students with a higher attendance rate are expected to have a lower risk of school suspension rates. The study shows that 95% of students attended to by mental clinicians on-site for four or more sessions have a reduced suspension rate as compared to the control group. In contrast to absenteeism there is not enough evidence to test the relationship between student mental health, or enrollment, or amenities on principal referrals. This is expected to be tested as a part of the statistical analysis.

Drop Out Rates

It is suspected that schoolyard improvements will lower dropout rates in high school settings. This hypothesis has not been broadly covered by literature. Drop-outs are an important data point investigated by school programs as an indication point for future unemployment and income prospects. Poor student mental health is considered a risk factor for students dropping out of school (Dupere et al., 2018). A Danish study by Hjorth et al. (2016) used a survey to understand educational levels across 3,146 participants. The study calculated odds ratios for mental health and related dropout levels in logistic regression models controlling for age, gender, educational level, parental education, parental income, and ethnicity. Results showed that students in higher education had a statistically significant higher risk (OR = 2.0) of dropouts with low mental health as compared to elementary level students. A similar study by Freudenberg (2007) in the United States uses a systematic review to assess strategies (structural, institutional, and organizational changes, curriculum changes, or changes in teacher support) for reducing school drop-out rates. The study recommends further quantifiable research to identify the health-related determinants of children dropping out of school. Its further hypothesis is that future research should cover the effect of student engagement on student graduation. With the availability of required data on student dropouts before and after the schoolyard introductions (between control and treatment school data, or prior-post intervention data), this hypothesis may be statistically assessed.

Enrollment Rates

Similar to dropout rates, an inverse relation is also suspected, that schoolyard improvements will help to retain students in public schools as they transition from elementary to middle school, and between grades, or increase enrollment as parents that previously have favored homeschooling or private schools may now favor schools in the district. Thus far, the literature does not contain a link indicating there is a positive effect. Enrollment rates have been used in literature as a complementary variable to understanding student absenteeism effects, drop-out or suspension risks from programs that improve mental health or student connectedness with the school environment (Bruns et al., 2004). The effect of the learning landscapes program can be statistically assessed empirically with enrollment data for schools on a control-treatment or prior-post basis. Though, a mechanistic system is likely not possible to model.

Improved Academic Achievement

The best available literature supports our hypothesis that schoolyard improvements may have a positive effect on student average test scores. This positive effect is expected to be brought about by increased time spent playing, a higher sense of emotional well-being at school, or other factors. The exact mechanical pathway does not need to be known to measure the effect size but can be hypothesized alongside results. Research has shown that exposure to nature and greening helps reduce mental fatigue, increases attention/concentration – that contribute to better academic learning (Kuo, Browning, and Penner, 2018) and reading performance (Otte et al., 2019). Browning and Rigolon (2019) examined 13 peer-reviewed articles to understand associations between academic outcomes, types of green spaces, and distances at which the green spaces were measured around schools. Greenness, and tree cover at the school and within 200 meters were associated with some increased academic performance especially in math and reading test scores (28% of outcomes).

Some reviewed papers have also had negative (8%) or inconclusive (64%) evidence on greenness impacts. A study by Kweon et al. (2016) assessed 219 public schools in D.C. to understand the effect of landcover on student performance using georeferenced data, controlling for socio-demographic data. The study showed that schools with more trees had a higher percentage of proficient or advanced scores in mathematics and reading standardized tests. Other types of "featureless" landscapes, grass/shrubs, paved surfaces, campus lawns, athletic fields showed no significant benefits on test scores in comparison. A similar study with the 387 schools in the Toronto District School Board (TDSB) with Grade 3 and 6 students showed that an increase in tree cover was responsible for a 13% variation in predicting mean student performance. These studies, even with variation in outcomes have shown the importance of urban forestry investments in school campuses especially with low green cover around the school.

Long Term Unemployment

Census data suggests unemployment is tied to dropout rates, among other outcomes like lifetime earnings. Through lowered dropout rates, the schoolyard improvements could have an effect on the probability of unemployment for former students. This is expected to be an outcome focus for high school students.

Historically there has been debate surrounding the influence of education quality on lifetime earnings and other labor market measures. This is the case because of the multitude of confounding factors that contribute to labor market outcomes like, wealth, family structure, parental income, race, gender, and more. Often unemployed youth arrive in that situation because of a poor family environment (Ramsadala et al., 2013).

Isolating the effect of any one factor is a difficult procedure. One such study attempting to isolate the effects of school quality found a link between unemployment and school quality for non-college-bound men (Eide & Showalter, 2008). Eide and Showalter found there was a relationship between school quality and unemployment in the decade post-graduation. However, this relationship did not last after the initial decade. They tested the effects of multiple school quality indicators - % of teachers with an advanced degree; school enrollment; pupil-teacher ratios; per student district expenditures; and school year length. They found that both pupil-teacher ratios and enrollment (size of the school) were significant contributors to avoiding unemployment. Interestingly, which variables mattered depended on which racial group was being analyzed (Eide & Showalter).

The link between years of schooling and unemployment has also been explored with attempts to find causality. Riddell and Song (2011) had used longitudinal data from the Current Population Survey and Census from 1980-2005 to determine how years of schooling could predict re-employment; the act of re-entering the workforce after exiting. The authors used the conscription risk of the Vietnam War and child labor law enactment as instrumental variables, to account for the endogeneity of education in an employment-education model. They found the probability of re-employment after a year of unemployment was higher for individuals who graduated high school, and that the percentage rose with each additional year of secondary schooling. Additionally, it was found that the duration of unemployment was shorter, and there were diminishing returns to workforce re-entry for additional years of schooling in post-secondary (Riddell & Song, 2011). This is of course conditional on the population studied, as they were facing a different employment landscape than today's youth. Nonetheless, a causal relationship has been estimated between employment and completion of high school.

The previous studies do not necessarily address the impact that schools with special programming have on unemployment. As Learning Landscapes goes beyond the typical requirements of a school to provide for its students, it is important to review what implications that may have. Catterall and Stern (1986) measured the effects of specific programming for dropout prevention. They found that these programs had an impact on high school dropouts. Further, they found that students participating in dropout-prevention programming were less likely to face unemployment.

Health & Wellness Outcomes

Health & Wellness Outcomes that were reviewed are improved physical health, increased play, increase in mood, increased nutrition, and improved physical health in the community. There is a good amount of literature on health and wellness outcomes, especially pertaining to increased play resulting from changes to the physical nature of schoolyards. Important gaps are the uncertain relationship between nutrition and school gardens, persistence of impacts into the future, and increases in school lunch sales. The ability of the econometric analysis to fill these gaps is still uncertain given data uncertainties, though lunch sales looks to be promising. It is important to note that the Autocase team has existing experience in the quantification of increased community health benefits resulting from increases in green space.

Student Mental Health - Increase in Mood

Improving schoolyard conditions, and adding green space and natural elements, is hypothesized to improve different aspects of childhood mental health and social interactions. Mental health factors into many of the outcomes in this literature review as a possibly mechanistic pathway. For example, though schoolyard improvements may not be tied to dropouts directly, the improvements are tied to an increase in mental health, and mental health is tied to decreases in dropout rates.

The literature reviewed heavily supports increases in mental health from schoolyard greening. A paper by Bates, Bohnert, and Gerstein (2018) supports this view through a behavioral mapping study. Though notably, there exists a multitude of confounding factors that influence the interaction between schoolyards and mental health. The research also usually depends on data collection in the form of surveying the student population, and analysis is dependent on this type of data.

In addition to school sites, community-level green space is an important influence on childhood mental health. In addition to general mental health, there is evidence that it could reduce the instances of ADHD symptoms (Amoly, et al, 2014).

School Lunch Sales

Increased participation in school lunches that include products from the school gardening program will be analyzed as a part of this study. An increase in potential spending within the school cafeteria between the control and treatment groups would have benefits to the school in terms of increased revenue or grants to actively improve and sustain these programs. To statistically analyze this, data would be required from the schools on outcomes or forecasted outcomes from these programs. As of yet, the literature assessed by Autocase hasn't had significant results on the impact of consumption of fruits and vegetables at school on direct student spending or the school grant funding.

An alternative approach looks at the quantified volumes of produce consumption. Food consumed y at school accounts for 35% of calories consumed by elementary students (Cotunga et al., 2012). However, studies have shown a low consumption of fruits and vegetables at school – an average consumption of 0.10 +/ 0.1 cup-equivalents of vegetables per day at a school lunch per student (Cotunga et al., 2012). A study by Cotunga, Manning, and DiDomenico (2012) analyzed the availability of school garden produce, and whether that tactic would increase children's consumption of vegetables at school lunch. They use a quasi-experimental design with 359 fourth and fifth-grade students using cafeteria observations on participants who continue to choose salads at lunch. The study showed an increase of 11-39% in students purchasing/selecting salads for their lunch at school as compared to the control group.

Nutrition

It is suspected that the school gardening program and schoolyard improvements will lead to higher health indicators amongst students. The availability of fresh produce (grown in the schoolyards) as a part of school lunches may contribute to a higher caloric intake per student. The literature reviewed thus far has been inconclusive on the caloric benefits - but has been more focused on self-reported questionnaires or tests on students' willingness to eat more vegetables and recognition of vegetables as a healthy source of food in younger children.

Some studies have found that increasing the amount of fruits and vegetables in the diets of adolescents has resulted in lower BMI, without any other interventions (Hart et al, 2010). However, increasing the intake of fruits and vegetables in the diet of children through educational programming is not necessarily sufficient to increase intake (Davis et al, 2021). It is more common to find that preference for fruits and vegetables, and attitudes towards their consumption improve. In a pre-and post-evaluation of elementary students, it was found that school gardening did increase the preference for these foods but had no impact on the amount consumed in the child's home (Lineberger & Zajicek, 2000). School gardening may have the additional benefit of increasing physical activity as well. In addition to higher preferences for fruits and vegetables, one study found that sedentary behavior was reduced through tracking students wearing accelerometers. This was in the absence of any other program designed to increase physical activity (Khan & Bell, 2019).

In the context of learning landscapes interventions that include school gardens, the provision of food through the cafeteria may be an important aspect in achieving reduced childhood obesity. However, the absence of any formal program, the presence, and involvement in school gardens can increase the knowledge children have of fruits and vegetables, which may lead to different food choices (Leuven et al., 2018).

In further research, a treatment effect was found only when school gardens existed alongside a formalized nutrition education program. Morgan et al. (2010) found through randomized control trials that the two needed to be coupled to achieve a significant impact on children's behavior. However, they only found an increase in the liking of vegetable taste and knowledge of vegetables. They were unable to find a lasting effect on the overall diets of children given the complex factors that influence a child's diet (Morgan et al., 2010).

Increased Play and Physical Health

It has been investigated formally by members of this team that the schoolyard improvements as part of the learning landscapes program resulted in an increase in play. This could be a pathway to other impacts like absenteeism, improved emotional wellbeing, increased test scores, etc.

Anthamatten et al. (2014) conducted a spatial analysis to determine the relationship between the density of playground features and moderate to vigorous physical activity. OLS methods were used to analyze data collected using SOPLAY best practices, for observing the physical activity. Children were observed at different levels of physical activity, recreating in different zones of the play area characterized by different features. They found that children increased physical activity in zones where there was more feature density (Anthamatten, P., et al, 2014).

Brink et al. (2010) conducted a similar study previously to investigate the effect of schoolyard improvements on childhood physical activity. Specifically, the authors used schools that were part of learning landscapes interventions, to compare them to control group schools. In a similar fashion, this study also analyzed the influence of different area types. Overall, it was found that the impact of learning landscapes interventions was both positive and significant. The authors also found that area type did have an influence on the increase in physical activity levels (Brink et al., 2010).

Engelen et al. (2013) explored the effects of adding loose materials to the school grounds in order to stimulate play, while also discussing with parents the risk associated with increases in these different types of play. The authors make the argument that while play with loose materials may be somewhat riskier from a short-term perspective, this is balanced by the long-term physiological benefits of increased childhood activity. They utilized mixed-effects regression to analyze accelerometer data and found that children engaged less in sedentary activities, and had more active playtime (Engelen et al., 2013).

Bundy et al. (2017) expanded on this research. The authors opted to use a cluster-randomized controlled trial rather than pre and post-treatment with the same subjects. While their results were similar they did not find that playtime increased definitively, however they note a large effect size, despite a statistically insignificant result ($p = 0.08$). They did however find significant differences in moderate to vigorous physical activity (MVPA), as well as reductions in sedentary play (Bundy et al., 2017).

With the help of Peter Anthamatten and a graduate student researcher, the team will revisit spatial analysis data to determine specific factors that affect the change in the play of students.

Community Outcomes

Community outcomes represented the largest gap in the literature, including very little in the way of quantitative or statistical analysis. This is likely due to the nebulous nature of measuring community cohesion, and family engagement. In the statistical analysis that will follow this literature review, reductions in vandalism and graffiti will be measured, as this demonstrates a change in attitude towards schoolyards within the community. It is important to note the Autocase team has existing experience evaluating changes in property value resulting from increasing green space.

Property Value

Green space investments improve the aesthetic quality of the surrounding area, creating a more desirable neighborhood. The best available scientific research shows that it is highly likely that property values near and far from the green infrastructure will increase from the incremental increase in aesthetic value of the schoolyard greening projects.

Environmental Outcomes

The environmental outcomes of importance such as Urban heat island reduction, habitat provision, carbon emissions impacts, and positive effects on air quality, were all left out of the literature review. The Autocase team has existing experience quantifying all of these outcomes resulting from changes in green space.

Urban Heat Island

Heatwaves are an increasing danger all across North America, sometimes resulting in large numbers of premature deaths (add Denver anecdote). These events may be more frequent and severe in the future due to climate change. Downscaled data creation is a method used by meteorologists to use global estimates, and convert them into grid-by-grid estimates for forecasted temperature given climate-change-related changes in carbon emissions.

The Urban Heat Island (UHI) effect compromises human health and comfort by causing respiratory difficulties, exhaustion, heatstroke, and heat-related mortality. Various studies have estimated that trees and other vegetation within building sites can reduce temperatures by 5 °F when compared to outside non-green space. At larger scales, variation between non-green city centers and rural areas has been shown to be as high as 9 °F during the day and up to 22 °F during the night. Green infrastructure (GI) can reduce the severity of extreme heat events by creating shade and reducing the amount of heat absorbed by pavement and rooftops, i.e. affecting the ambient temperature. Even a small cooling effect can be sufficient to reduce heat stress-related fatalities during extreme heatwave events.

The statistical analysis may use data points such as changes in ambient temperature around the school before and after greening, increase in shading, and canopy cover to ascertain the benefits of learning landscapes towards reducing urban heat islands near the schools.

Carbon Sequestration & Air Quality

A vegetated cover provides the benefit of carbon sequestration. This occurs through the accumulation of carbon in above and below-ground plant biomass as well as in the soil beneath the vegetation as soil organic carbon. Carbon sequestration values are reported in terms of a rate of mass over a given unit of time for a unit of area. The greater the area that is covered in vegetation and the longer the vegetation persists, the greater the amount of carbon that is sequestered. The rate at which carbon is sequestered depends on the type of vegetation. Larger plants sequester more carbon as they have more above and below-ground biomass both of which store carbon. Carbon also accumulates in the soil as the vegetation grows.

Literature has also shown there to be different rates of sequestration depending on whether or not the vegetation is managed or unmanaged, with unmanaged vegetation having higher sequestration rates. Some data that may be used to evaluate carbon sequestration potential at school sites would include continuous variables to speak to the acreage of green space, types of greening on-site or canopy coverage, as well as binary variables of whether the green space was managed or unmanaged overtime after construction.

Pollinator Benefits

Increased green space is responsible for increasing habitat for pollination, thereby increasing environmental benefits. This is commonly referred to as a contribution towards improved ecosystem services.

Composting Programs

Increased availability in green spaces and outdoor learning is expected to increase volunteer or student activities such as composting. Some data on the pre and post initiatives into composting would be needed, maybe in terms of tons of composting material collected. There would be a supplementary reduced need to carry waste offsite, GIS data may be useful to estimate miles to the nearest landfill in the district.

Student outcomes to tangible changes in student behavior, health, activities, and academic outcomes that may be reviewed as a part of the statistical analysis. It includes increased time spent outdoors in terms of playtime, changes in academic performance in terms of standardized test scores, increased nutrition from available garden produce in the cafeteria, mental health and well being, and a more qualitative nuance - the long term unemployment considerations from changes in drop out rates / academic performance, and student engagement.

Bibliography

Bates, C. R., Bohnert, A. M., & Gerstein, D. E. (2018). Green Schoolyards in Low-Income Urban Neighborhoods: Natural Spaces for Positive Youth Development Outcomes. Frontiers in psychology, 9, 805. https://doi.org/10.3389/fpsyg.2018.00805

Louise Chawla, Kelly Keena, Illène Pevec, Emily Stanley, Green schoolyards as havens from stress and resources for resilience in childhood and adolescence, Health & Place, Volume 28, 2014, Pages 1-13, ISSN 1353-8292, https://doi.org/10.1016/j.healthplace.2014.03.001.

Brookmeyer, K. A., Fanti, K.A., & Henrich, G. C. (2006). Schools, parents, and youth violence: A multilevel, ecological analysis. Journal of Clinical Child and Adolescent Psychology, 35, 504–514.

Amoly E., Dadvand P, et al. (2014). Green and Blue Spaces and Behavioral Development in Barcelona Schoolchildren: The BREATHE Project. Environmental Health Perspectives, 122(12).
Doi: 10.1289/ehp.1408215.

Maas J, Verheij RA, Groenewegen PP, *et al*Green space, urbanity, and health: how strong is the relation?*Journal of Epidemiology & Community Health* 2006;**60:**587-592.

Peters, K, Elands, B and Buijs, A. 2010. Social interactions in urban parks: Stimulating social cohesion? *Urban For Urban Green* 9(2): 93–100. DOI: https://doi.org/10.1016/j.ufug.2009.11.003

Stevenson, KT, Peterson, MN, Bondell, HD, Mertig, AG and Moore, SE. 2013. Environmental, institutional, and demographic predictors of environmental literacy among middle school children. Patterson RL, editor. Plos One 8(3): e59519. DOI: https://doi.org/10.1371/journal.pone.0059519

Chawla, L. 2015. Benefits of Nature Contact for Children. In: Nasar, JL (ed.), J Plan Lit 30(4): 433–452. DOI: https://doi.org/10.1177/0885412215595441

Li, M. (2005). High school completion and future youth unemployment: new evidence from High School and Beyond. doi:10.1002/jae.817

Ramsadala, G., Rikke, G., and Wynn, R. (2013). Dropout and early unemployment. International Journal of Educational Research, 62: 75-86. Doi: 10.1016/j.ijer.2013.06.011

Eide, E., and Showalter, M. (2008). Does Improving School Quality Reduce The Probability Of Unemployment? *Contemporary Economic Policy*. Doi: 10.1093/cep/byi042

Riddell, W. Craig; Song, Xueda (2011) : The impact of education on unemployment incidence and re-employment success: Evidence from the US labour market, IZA Discussion Papers, No. 5572, Institute for the Study of Labor (IZA), Bonn, http://nbn-resolving.de/urn:nbn:de:101:1-201104133943

Merrick, M. et al. (2019). Vital Signs: Estimated Proportion of Adult Health Problems Attributable to Adverse Childhood Experiences and Implications for Prevention — 25 States, 2015–2017. MMWR Morb Mortal Wkly Rep; 68(44): 999–1005. doi: 10.15585/mmwr.mm6844e1

Catterall, J. and Stern, D. (1986). The Effects of Alternative School Programs on High School Completion and Labor Market. Educational Evaluation and Policy Analysis, 8(1): 77-86. Retrieved: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.877.8642&rep=rep1&type=pdf

Davis, J.N., Pérez, A., Asigbee, F.M. et al. School-based gardening, cooking and nutrition intervention increased vegetable intake but did not reduce BMI: Texas sprouts - a cluster randomized controlled trial. Int J Behav Nutr Phys Act 18, 18 (2021). https://doi.org/10.1186/s12966-021-01087-x

Leuven, J., Rutenfrans, A., Dolfing, A. G., & Leuven, R. (2018). School gardening increases knowledge of primary school children on edible plants and preference for vegetables. *Food science & nutrition*, *6*(7), 1960–1967. https://doi.org/10.1002/fsn3.758

Morgan, Philip & Warren, Janet & Lubans, David & Saunders, Kristen & Quick, Garbrielle & Collins, Clare. (2010). The impact of nutrition education with and without a school garden on knowledge, vegetable intake and preferences and quality of school life among primary-school students. Public health nutrition. 13. 1931-40. 10.1017/S1368980010000959.

Khan, M., & Bell, R. (2019). Effects of a School Based Intervention on Children's Physical Activity and Healthy Eating: A Mixed-Methods Study. International journal of environmental research and public health, 16(22), 4320. https://doi.org/10.3390/ijerph16224320

Lineberger, S., and Zajicek, J. (2000). School Gardens: Can a Hands-on Teaching Tool Affect Students' Attitudes and Behaviors Regarding Fruit and Vegetables? HortTechnology, 10(3). doi:10.21273/HORTTECH.10.3.593

Hart, C.N., et al. (2010) Early Patterns of Food Intake in an Adolescent Weight Loss Trial as Predictors of BMI Change. Eat Behav. 2010 Dec; 11(4): 217–222.doi: 10.1016/j.eatbeh.2010.05.001

Browning, Matthew H.E.M.; Rigolon, Alessandro (2019). School Green Space and Its Impact on Academic Performance: A Systematic Literature Review. International Journal of Environmental Research and Public Health, 16(3). doi:10.3390/ijerph16030429

Kuo et al. (2018). Might School Performance Grow on Trees? Examining the Link Between “Greenness” and Academic Achievement in Urban, High-Poverty Schools

Kweon, B.-S., Ellis, C. D., Lee, J., & Jacobs, K. (2017). The link between school environments and student academic performance. Urban Forestry & Urban Greening, 23, 35–43

Sivarajah, S., Smith, S. M., & Thomas, S. C. (2018). Tree cover and species composition effects on academic performance of primary school students. PloS one, 13(2), e0193254.

Stevenson, K., et al. (2020) A national research agenda supporting green schoolyard development and equitable access to nature. Science of the Anthropocene, 8(1). doi:10.1525/elementa.406

Brink, L. et al. (2010). Influence of Schoolyard Renovations on Children’s Physical Activity: The Learning Landscapes Program. American Journal of Public Health, 100(9). DOI: 10.2105/AJPH.2009.178939

Anthamatten, P., et al. (2014). A Microgeographic Analysis of Physical Activity Behavior Within Elementary School Grounds. American Journal of Health Promotion, 28(6). DOI: 10.4278/ajhp.121116-QUAN-566

Engelen, L., et al. (2013). Increasing physical activity in young primary school children — it's child's play: A cluster randomised controlled trial. Preventative Medicine, 56(5). Doi: 10.1016/j.ypmed.2013.02.007

Bundy, A. (2017). Sydney Playground Project: A Cluster-Randomized Trial to Increase Physical Activity, Play, and Social Skills. Journal of School Health, 87(10). Doi: 10.1111/josh.12550

EPA Waste Reduction Model (WARM).

Nancy Cotugna, Carolyn K. Manning & James DiDomenico. (2012). Impact of the Use of Produce Grown in an Elementary School Garden on Consumption of Vegetables at School Lunch, Journal of Hunger & Environmental Nutrition, 7:1, 11-19, DOI: 10.1080/19320248.2012.649668

Hjorth, C.F., Bilgrav, L., Frandsen, L.S. *et al.* Mental health and school dropout across educational levels and genders: a 4.8-year follow-up study. *BMC Public Health* 16, 976 (2016). https://doi.org/10.1186/s12889-016-3622-8

Freudenberg, N., and Ruglis, J. (2007). Reframing School Dropout as a Public Health Issue. Preventing Chronic Disease, 4(4).

Bibliography of Unused Sources

Bikomeye, J.C., Balza, J., and Beyer, K.M. (2021). The Impact of Schoolyard Greening on Children's Physical Activity and Socioemotional Health: A Systematic Review of Experimental Studies
International. Journal of Environmental Research and Public Health, 18(2). doi.org:10.3390/ijerph18020535

Kelz, C., Evans, G.W., Roderer, K. (2013). The Restorative Effects of Redesigning the Schoolyard: A Multi-Methodological, Quasi-Experimental Study in Rural Austrian Middle Schools
doi:10.1177/0013916513510528

Damerell, P., Howe, C., Milner-Gulland, E.J., (2013). Child-orientated environmental education influences adult knowledge and household behaviour. Environmental Research Letters, 8(1), 1-15. DOI:10.1088/1748-9326/8/1/015016

Norton, C. L., Watt, T. T., (2014). Exploring the impact of a wilderness-based positive youth development program for urban youth. Journal of Experiential Education, 37(4), 335 - 350.doi:10.1177/1053825913503113

Delia, J., Krasny, M.E., (2018). Cultivating positive youth development, critical consciousness, and authentic care in urban environmental education. Frontiers in Psychology, 15. Doi: 10.3389/fpsyg.2017.02340

Cohen, D.A., Han, B., Isacoff, J., Shulaker, B., Williamson, S., (2019). Renovations of neighbourhood parks: Long-term outcomes on physical activity. Journal of Epidemiology & Community Health, 73, 214-218. DOI: 10.1136/jech-2018-210791

Zhang, Y., et al. (2020). The Association between Green Space and Adolescents' Mental Well-Being: A Systematic Review. International Journal of Environmental Research and Public Health, 17(18). doi:10.3390/ijerph17186640

Qutub, S., et al. Adolescent Girls' Choices in Schoolyard Activity in Urban Pakistan. Children, Youth, and Environments, 25(3). Doi: 10.7721/chilyoutenvi.25.3.0040

Monahan, K.C., et al. (2014). From the School Yard to the Squad Car: School Discipline, Truancy, and Arrest. Journal of Youth and Adolescence, 43. Retrieved from: https://link.springer.com/article/10.1007%2Fs10964-014-0103-1

Timperio, A., Jeffery, R. W., Crawford, D., Roberts, R., Giles-Corti, B., Ball, K., (2010). Neighbourhood physical activity environments and adiposity in children and mothers: A three-year longitudinal study. International Journal of Behavioral Nutrition and Physical Activity, 7(18). Retrieved from: https://ijbnpa.biomedcentral.com/articles/10.1186/1479-5868-7-18.

White, R.L., Eberstein, K., Scott, D.M., (2018). Birds in the playground: Evaluating the effectiveness of an urban environmental education project in enhancing school children's awareness, knowledge and attitudes towards local wildlife. PLoS ONE, 13(3).doi:10.1371/journal.pone.0193993.

Lopez, R., Campbell, R., Jennings, J. (2008). Schoolyard Improvements and Standardized Test Scores: An Ecological Analysis. Gaston Institute Research Paper.

Bates, C.R., Bohnert, A.M., Gerstein, D.E., (2018). Green schoolyards in low-income neighborhoods: Natural spaces for positive youth development outcomes. Frontiers in Psychology, 9. doi:10.3389/fpsyg.2018.00805.

Mennis, J., Mason, M., Ambrus, A., (2018). Urban greenspace is associated with reduced psychological stress among adolescents: A Geographic Ecological Momentary Assessment (GEMA) analysis of activity space. Landscape and Urban Planning, 174, 1-9. doi: 10.1016/j.landurbplan.2018.02.008

Anderson, C. L., Monroy, M., & Keltner, D. (2018). Awe in nature heals: Evidence from military veterans, at-risk youth, and college students. Emotion, 18(8), 1195–1202. https://doi.org/10.1037/emo0000442

Jensen, A.K., Olsen, S.B., (2019). Childhood nature experiences and adulthood environmental preferences. Ecological Economics, 156, 48-56. DOI: 10.1016/j.ecolecon.2018.09.011

Lopez, R., Campbell, R., Jennings, J. (2008). The Boston Schoolyard Initiative: A Public-Private Partnership for Rebuilding Urban Play Spaces. Journal of Health Politics, Policy, and Law, 33(3). doi:10.1215/03616878-2008-010

Faber, T., Wilmseyer, C.B., (2020) . Self-regulation gains in kindergarten related to frequency of green schoolyard use. Journal of Environmental Psychology, 70 doi:10.1016/j.jenvp.2020.101440

Largo-Wight, E., Guardino, C., Wludyka, P.S., Hall, K.W., Wight, J.T., Merten, J.W., (2018). Nature contact at school: The impact of an outdoor classroom on children's well-being. International Journal of Environmental Health Research, 28(6), 653-666. Doi: 10.1080/09603123.2018.1502415

Ernst, J., Burcak, F., (2019). Young children's contributions to sustainability: The influence of nature play on curiosity, executive function skills, creative thinking, and resilience. Sustainability, 11(15). doi:10.3390/su11154212

Taye, F. A., Abildtrup, J., Mayer, M., Ščasný, M., Strange, N., & Lundhede, T. (2019). Childhood experience in forest recreation practices: evidence from nine European countries. Urban Forestry and Urban Greening, 46, [126471]. https://doi.org/10.1016/j.ufug.2019.126471

Chalwa, L. et al. (2014). Green schoolyards as havens from stress and resources for resilience in childhood and adolescence. Health and Place, 24. doi:10.1016/j.healthplace.2014.03.001

Christiansen, L.B. (2017). Schoolyard upgrade in a randomized controlled study design—how are school interventions associated with adolescents' perception of opportunities and recess physical activity. Health Education Research, 32, (1). doi:10.1093/her/cyw058

Bennet, P.R., Lutz, A.C., Jayarami, L. (2012). Beyond the Schoolyard: The Role of Parenting Logics, Financial Resources, and Social Institutions in the Social Class Gap in Structured Activity. Sociology of Education, 85(2). doi:10.1177/0038040711431585

Kuo, M., et al. (2021). Greening for academic achievement: Prioritizing what to plant and where. Landscape and Urban Planning, 206. doi:10.1016/j.landurbplan.2020.103962